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[THIRD SERIES.]

ART. XXVII.—*Contributions to Meteorology;* by ELIAS LOOMIS, Professor of Natural Philosophy in Yale University. Twenty-third paper.

[Read before the National Academy of Sciences, Nov. 14, 1888.]

Relation of rain-areas to areas of high and low pressure.

1. IN former papers (Nos. 6, 7, 12, 17 and 18) I have investigated the circumstances attending remarkable rain-falls both in the United States and Europe, and obtained some important results. Since the publication of those papers, the materials suited to this inquiry have greatly increased, and I have revised the investigation, availing myself of all the materials within my reach. The published volumes of Signal Service tri-daily observations embrace a period of 41 months, whereas when I prepared papers 6 and 7, only 15 months' observations had been published. The observations of 41 months show 106 cases in which there was a rain-fall of at least two inches in eight hours, at some station east of the Rocky Mountains, and North of the parallel of 36 degrees. These cases were distributed by seasons as follows: Winter, 7; Spring, 14; Summer, 53; and Autumn, 32; which shows that great rains occur most frequently during that period of the year in which the atmosphere contains the greatest amount of vapor.

Great rain-falls occur much more frequently near the Atlantic coast, than they do at interior stations. Of the 106 cases compared, 60 occurred on or near the Atlantic coast, and 46 at the interior stations. As there were numerous changes in the stations during the period of the observations, the ratio of the number of the interior stations to the coast stations was variable; but for the entire period, the former were nearly three times as numerous as the latter; showing that near the Atlantic coast north of Latitude 36°, great rain-falls occur *four* times as frequently as in the interior of the United States, east of the Rocky Mountains.

2. The rain-areas were generally associated with areas of low pressure, and the rain center was generally on the east side of the low center. The number of cases for each of the four quadrants was as follows:

Rain center in the N.E. quadrant,	30	per cent of the whole number.	
S.E. "	28	" "	"
N.W. "	9	" "	"
S.W. "	9	" "	"
The two centers coincident,	24	" "	"

The greatest rains are generally associated with areas of low pressure of only moderate depression. For the cases which occurred during the winter months, the average height of the barometer at the low center was 29·50 inches; and for the cases which occurred during the summer months, the average height of the barometer at the low center was 29·70 inches. In only one case did the barometer sink as low as 29 inches, although in the United States and Canada the barometer sinks below 29 inches on an average 17 times annually, as indicated by tri-daily observations.

Generally a rain-fall amounting to two inches in eight hours does not last more than eight hours, either at the same station or at any neighboring station. Among the 106 cases compared, there were only five cases in which two inches of rain fell in two successive periods of eight hours at the same station, and there were four other cases in which two inches of rain fell in the succeeding eight hours at a second station so near the first station, that the rain may be presumed to have fallen at this rate uninterruptedly for sixteen hours or more.

3. During the period of 41 months' observations, there were 67 cases in which there was a rain-fall of at least 2½ inches in eight hours at stations east of the Rocky Mountains, and south of the parallel of 36°. These cases were distributed by seasons as follows: Winter, 4; Spring, 9; Summer, 22; and Autumn, 32. The greatest number of cases occurred in the autumn, while north of Lat. 36° the greatest number occurred in summer. South of Lat. 36° the month of greatest frequency is September, while north of Lat. 36° the month of greatest frequency is July, but August shows an almost equal number of cases. The difference therefore in the date of maximum frequency for the northern and southern parts of the United

States, is not very great, and may disappear in a longer series of observations.

These great rain-falls occur somewhat more frequently near the coast of the Atlantic or the Gulf of Mexico than at interior stations. Of the 67 cases compared, 46 occurred on or near the coast, and 21 occurred at interior stations. During the period of these observations, the number of coast stations was somewhat greater than the interior stations, and the average number of great rain-falls at the coast stations was about one-half greater than at interior stations.

The rain center was generally on the east side of the low center, and the number of cases for each of the four quadrants was as follows:

Rain center in the N.E. quadrant,	34	per cent of the whole number.	
S.E. "	21	"	" "
N.W. "	5	"	" "
S.W. "	18	"	" "
The two centers coincident,	22	"	" "

The most noticeable difference between these results and those for the northern portion of the United States is a less number of cases in the S.E. quadrant, and a greater number in the S.W. quadrant. This difference may perhaps be ascribed to the fact that in the southern portion of the United States, the Gulf of Mexico is an important source of the vapor which is precipitated, while in the northern portion, the Atlantic Ocean affords the principal supply.

Among the 67 cases under examination, there is only one case in which two and a half inches of rain fell in two successive periods of eight hours at the same station, and there are three other cases in which two and a half inches fell in a second period of eight hours at a station near the first. Thus we see that while heavy rains are of more frequent occurrence in the southern part of the United States than they are in the northern part, they have a less period of duration.

The depression of the barometer accompanying great rain-falls is not very great, the average pressure at the low center being 29·63 inches for that part of the United States north of Lat. 36°; and 29·77 inches for that part of the United States south of Lat. 36°.

4. In order to show what effect is produced upon the rain-fall by an extraordinary depression of the barometer, I have examined all the cases in which the barometer fell below 29 inches, at any station in the United States or Canada, during the period from September, 1872, to June, 1884. The number of such cases is 131, and the average rain-fall in 24 hours at all these stations was 1·58 inches, and the greatest rain-fall at any of the stations was 4·32 inches. At 38 of the stations the

rain-fall exceeded two inches, and at 34 stations the rain-fall was less than one inch. In all of the cases in which the rain-fall did not amount to one inch in 24 hours at any of the stations, the center of low pressure was over the Atlantic Ocean, or very near the coast. In these cases the eastern segment of the low area was over the Atlantic Ocean where the amount of the precipitation could not be measured; and we have found that the greatest rain-fall almost invariably occurs in this eastern segment. When the low center was over the interior of the continent, the average rain-fall at the principal rain centers was 2·48 inches; so that it seems reasonable to conclude that if we had observations from all parts of each of the 131 low areas, the average rain-fall for the principal rain centers would not be less than two and a half inches in 24 hours. Even this amount does not seem very large in comparison with the rain-fall accompanying an average depression of 29·63 inches; and we seem forced to conclude that a moderate depression of the barometer is as favorable to great rain-fall as an extremely great depression. This may appear to indicate that rain-fall has but little connection with barometric depressions. It should, however, be remembered that the depression at the center of a low area depends not merely upon the barometric gradient, but upon the geographical extent of the low area. If at the center of a low area having a diameter of 1000 miles, the depression of the barometer is one-half inch below the mean, at the center of a low area having a diameter of 2000 miles, with the same barometric gradient, the depression would be an entire inch below the mean. In the United States, when the barometer sinks below 29 inches, the average diameter of the areas of low pressure is 2140 miles; but when the lowest isobar is 29·5 inches, the average diameter of the low areas is 1185 miles; which shows that when the barometer is most depressed, the average barometric gradient is but little greater than it is with a moderate depression. Extreme depressions of the barometer are generally due to an unusual geographical extent of the low areas, and it appears that great rain-falls depend upon the barometric gradient more than they do upon the geographical extent of the low areas.

5. I next examined those cases in which the total rain-fall for all the stations was uncommonly great. From September, 1872, to November, 1873, I selected those cases in which the total rain-fall at all the stations east of the Rocky Mountains, amounted to at least nine inches in eight hours; from December, 1873, to January, 1875, I selected those cases in which the total rain-fall amounted to at least ten inches in eight hours; from January, 1877, to June, 1877, eleven inches; and from July, 1877, to December, 1877, twelve inches in eight hours.

This change in the amount of rain-fall adopted as the standard was rendered necessary by the gradually increased number of the stations of observation.

The number of cases of rain-fall which fulfilled the preceding conditions was 106. The geographical extent of some of these rain areas was remarkable. In ten cases the area of one inch rain-fall was at least 500 English miles in length; and in three cases it exceeded 700 miles in length. Frequently the entire rain-area is an oval figure whose length exceeds 1000 miles, and whose breadth exceeds 500 miles.

These 106 cases were distributed by seasons as follows: Winter, 30 cases; Spring, 19; Summer, 15; and Autumn, 42. These great rain areas are thus seen to be most frequent in Autumn, and the month of greatest frequency is November. We have found that excessive rains at single stations are most common from July to September.

6. The directions of the station of greatest rain-fall from the point of minimum pressure were as follows:

Rain center in the	S.E. quadrant,	40	per cent of the whole number.
	N.E. "	37	" " "
	S.W. "	10	" " "
	N.W. "	3	" " "
Direction nearly	South,	4	" " "
	East,	5	" " "
	North,	1	" " "

We see that the greatest rain-fall generally occurred on that side of the center of low pressure towards which the low area was advancing; that is, the low center moved towards the rain area. In about 60 per cent of the whole number of cases, these two directions were inclined to each other less than 60°. This coincidence would have been more frequent, if the direction of progress of the low centre had been compared with the direction of the greatest rain area, instead of the station of greatest rain-fall; for frequently the station of greatest rain-fall was not included in the greatest rain area. In several of the cases in which the principal rain center was on the west side of the low center, the geographical extent of the rain areas on the east side was greater than that on the west side. This fact seems to indicate that the general movement of the winds depends more upon the geographical extent of the rain areas, than upon the quantity of rain which falls at a single station. In two cases when the rain center was in the northwest quadrant, the center of least pressure moved towards the northwest, which appears to indicate very distinctly the tendency of a low center to incline towards a rain area. When the station of greatest rain-fall was southwest of the center of minimum pressure, the rain-fall on the southwest side accompanied the advance of an area of high pressure, with winds from the northwest quarter supplanting the southerly winds which had preceded. The barometric gradients within the rain areas were small, and the rain-fall in the southwest quadrant had but little influence in determining the general movement of the winds about the low center, because the southerly winds were soon supplanted by the advancing west and northwest winds.

7. There is generally a marked uniformity in the changes of pressure and temperature accompanying the eastward progress of an area of low pressure. In front of the low area the pressure diminishes, and in the rear the pressure increases. For the 106 cases under examination, the average diminution of pressure in eight hours on the front side of the storm was 0·24 inch, and the average increase of pressure on the rear side was 0·12 inch. For different storms, however, those numbers were very unequal. In some of the cases the barometer fell more than half an inch in eight hours in front of the storm, and in one case the barometer fell 0·86 in eight hours. On the other hand there were several cases in which the barometer remained nearly stationary during the eight hours preceding the approach of the low center.

There were four cases in which the rise of the barometer in the rear of the storm exceeded 0·40 inch in eight hours. There were several cases in which for eight hours the barometer was almost entirely stationary in the rear of the storm; and there were two cases in which there was an average diminution of pressure amounting to four or five hundredths of an inch during the eight hours succeeding the passage of the storm's center. These cases, in which the pressure remained nearly stationary for eight hours preceding or following the low center, generally resulted from the interference of a second area of low pressure. When an area of low pressure is preceded by a second area of low pressure, within a distance of a few hundred miles, the fall of the barometer in front of the first low center is generally very small; and when an area of low pressure is followed immediately by a second area of low pressure, the rise of the barometer in the rear of the first low center is generally very small.

8. For the 106 cases under examination, there was an average rise of the thermometer amounting to seven degrees during the twenty-four hours preceding the approach of the low center; and there was an average fall of eight degrees during the succeeding twenty-four hours. These numbers, however, fluctuated from twenty-eight degrees to zero, over a large geographical area, and in individual cases the fluctuations were considerably greater. In a few cases there was a noticeable correspondence between the magnitude of the barometric and thermometric fluctuations attending the progress of a low

center, but generally such a correspondence was not very distinctly marked; the changes of temperature being often due to causes which had but little influence upon the barometer.

9. A single rain-area seldom occurs alone. In 90 per cent of the 106 cases of great rain-fall under examination, there was more than one rain-area east of the Rocky Mountains with at least a half inch rain-fall, and if we include smaller rain areas, the percentage is still greater. In 36 per cent of the whole number of cases, there were at least four rain-areas with not less than a half inch rain-fall; in 9 per cent of the cases there were at least six rain-areas with not less than a half inch rain-fall; and in one case (Sept. 11.3, 1872), there were eight rain-areas all of which exceeded a half inch. These facts suggest the idea that those conditions which are favorable to rain-fall at one locality, are generally favorable to rain-fall over a much larger district. Extensive rains frequently result from an unstable condition of the atmosphere, in consequence of which the stratum of air near the earth's surface tends to ascend. This unstable condition may result from a temperature above the mean for the given time and place, and it may also result from the presence of an unusual amount of aqueous vapor. These conditions of unusual heat and unusual humidity often prevail simultaneously over an area several hundred miles in diameter. Over such a region the entire stratum of air near the earth's surface tends to ascend. A general ascent of the air over a large area is impossible, but some local cause may determine an upward movement at some point in this area, and the surrounding air will be drawn in to supply the place of the air which ascends. The vapor of the ascending air will be cooled by elevation, and be precipitated, and thus may commence a shower which under favorable conditions will increase and continue for several hours. When this unstable condition of the air prevails over a large area, there may be more than one point where such an ascending current is formed, and thus we may have several rain-areas prevailing simultaneously within a few hundred miles of each other.

Rain-areas, with a total rain-fall of 6 or 7 inches in eight hours for all the stations east of the Rocky Mountains, seldom continue for more than 24 hours; only five such cases having been found in a period of 41 months, and there were only six cases in which the rain-center continued at the same station for a period of 16 hours. These facts seem to indicate that the causes which produce rain do not derive increased force from the rain-fall for an indefinite period of time, but after a few hours they expend themselves and become exhausted.

10. The preceding examination of great rain-storms seems to warrant some generalizations respecting the conditions favorable for rain-fall.

A. One of the most common causes of rain is an unstable condition of the atmosphere resulting from an unusually high temperature combined with unusual humidity. This condition of the atmosphere is most frequently found where the barometric pressure is somewhat below the mean, although it sometimes extends beyond the isobar of 30 inches. It is most frequently found in the eastern segment of the low area, and is generally accompanied by easterly or southerly winds.

B. Another very common cause of rain, and one which is frequently associated with the former, is a cold northerly or westerly wind in the western segment of the low area. This cold wind pushes under the warm and humid wind which prevails in the eastern segment of the low area, and lifts it up from the earth's surface to such a height, that a considerable portion of its vapor is condensed. Frequently there is direct evidence that the westerly winds in the rear of a storm are merely surface winds, and that the southeast winds which prevailed in front of the storm extended to the rear occupying a stratum of considerable elevation. It is generally difficult to obtain evidence of the direction of the upper stratum of air, while a rain-storm is prevailing at the surface of the earth; but occasionally there are breaks in the lower stratum of clouds which enable us to observe the movement of the upper clouds. The observations on Mt. Washington afford us at all times the means of comparing the winds at low stations with the winds at the height of 6000 feet. We frequently find that the latter winds are from the south or southeast, while the surface winds are from the north or west.

C. Proximity to the ocean or to a large inland sea is favorable to rain-fall. We have seen that heavy rains are more frequent near the coast of the Atlantic ocean and the Gulf of Mexico, than they are at interior stations.

The following facts seem well established:

D. No great barometric depression with steep gradients ever occurs without considerable rain. This is true not only for the United States, but also for the cyclones of the West Indies, for those of the China sea, of India and the Bay of Bengal.

E. In great rain-storms the barometric pressure generally diminishes, while the rain-fall increases.

F. The greatest depression of the barometer generally occurs about twelve hours after the greatest rain-fall.

G. A great fall of rain is favorable to a rapid progress of the center of least pressure, while a small rain-fall is generally attended by a less rapid progress. It is, however, plain that the rate of progress of a low center depends partly upon other causes than the amount of rain-fall.

11. In my 7th paper I have shown that considerable depres-

sions of the barometer sometimes occur without rain, or at most with very little rain. This result is confirmed by 41 months of Signal Service tri-daily observations, which furnish 130 cases in which the total rain-fall, at all the stations east of the Rocky Mountains, was less than one-tenth of an inch in 8 hours. For a period of 40 hours from October 19.3 to 21.1, 1872, the total rain-fall, at all the stations east of the Rocky Mountains, was only 0·11 inch. An area of low pressure prevailed throughout the northwest, and the barometer at St. Paul fell to 29·57. The temperature at LaCrosse rose 27° above the normal. Throughout this low area not a drop of rain was reported during these 40 hours. For a period of 32 hours from May 6.3 to May 7.3, 1874, the total rain-fall at all the stations east of the Rocky Mountains was only 0·07 inch. The barometer at Fort Sully fell to 29·44, and the temperature rose 22° above the normal. From May 6.1 to May 8.3, a period of 72 hours, the rain-fall within the area of low pressure was only 0·09 inch. It may be said that these cases of low pressure generally occurred in that region where the stations of observation are widely separated, and that rain may have fallen at intermediate points where there was no observer. The long continuance of the rainless condition, in the cases just mentioned, is pretty conclusive evidence that the fall of rain must have been very slight over the entire area of low pressure. The month of October, 1872, was one of unusual drought throughout the whole of the northwestern part of the United States. During the first 27 days of the month, no rain fell at St. Paul, there was only 0·02 inch at Fort Sully, and only 0·09 inch at Omaha. From Feb. 8.2 to 10.3, 1877, a period of 64 hours, the total rain-fall at all the stations east of the Rocky Mountains was only 0·62 inch. An area of low pressure prevailed throughout the northwestern part of the United States (Bar. 29·51 at Bismark), and within this low area not a drop of rain was reported during these 64 hours. The thermometer at St. Paul rose 23° above the normal.

12. These examples are sufficient to show that in the northwestern part of the United States (east of the Rocky Mountains) there are sometimes formed areas of low pressure having great geographical extent, and accompanied by an amount of rain which is extremely small. Throughout nearly the whole extent of these low areas the average temperature was above the normal, and in the neighborhood of the low center it was 20° above the normal. We cannot ascribe this unusual temperature to the heat developed in the condensation of aqueous vapor. We must ascribe it to the direct effect of the sun's rays acting upon the sandy soil of the northwestern plains. These low areas in the northwest were all attended by an area

of high pressure on the east or southeast side, where the average height of the barometer was 30·36 inches. This high temperature over the northwestern plains, combined with an area of high pressure on the east or southeast side, is sufficient to cause a general movement of the surrounding air towards the heated region. The Signal Service maps are too limited in extent to show what were the atmospheric conditions on the north and west sides of the low area; but we must conclude that the colder air from the north would press down to displace the warmer air of the low area. Thus we find all the forces requisite to generate a cyclonic movement of the winds about the center of the heated region. The heat of the central area is continually recruited by the direct action of the sun's rays, and thus the cyclonic movement of the low area may be maintained for a long time, while the steady pressure of the air on the western side (arising from the same causes which determine the average system of circulation of the winds) fills up the low area on its western side, and thus crowds the low area slowly eastward.

13. If areas of low pressure of great geographical extent may be formed and maintained for several days with very little rain, is there no difference between the low areas which are attended by a heavy rain-fall, and those which are attended by very little rain? Differences do exist and generally they are strongly marked. The following are some of them:

Characteristics of areas of low pressure.

With excessive rain-fall.	With little or no rain.
a. Steep barometric gradients.	*a.* Feeble barometric gradients.
b. Violent winds.	*b.* Moderate winds.
c. Rapid changes of barometric pressure.	*c.* Slow changes of barometric pressure.
d. Rapid progressive movement.	*d.* Slow progressive movement.

These are the characteristics of an area of low pressure which stands alone, uninfluenced by the proximity of a second area of low pressure. When two areas of low pressure are formed near each other, their movements are often very complicated.

14. In my eighteenth paper, I investigated the relation of rain-fall to barometric pressure in Europe, as shown by the observations contained in the International Bulletin. A more extensive comparison of observations has led to conclusions differing but little from those stated in my former paper.

If we could have similar observations of the rain-fall over all parts of the Atlantic Ocean, they would be of great value in determining the influence of rain-fall upon barometric pressure. As such observations have never been made, I have sought for the best available information bearing upon this question.

This I have derived from the Atlantic Weather Charts from Aug. 1, 1882, to Sept. 3, 1883, published under the authority of the British Meteorological Council. These maps show for each day the region where showers prevailed and where rain prevailed. I have selected all the cases in which there is marked upon these maps a rain area more than 600 English statute miles in length, omitting the tropical regions. The number of these cases is 375. In order to exhibit more clearly the character of the results, I have divided the cases into seven groups. Group **A** contains 29 cases in which the center of the rain area coincided nearly with a center of low pressure; group **B** contains 161 cases in which the rain was associated with an area of low pressure, chiefly on its eastern side; group **C** contains 46 cases in which the rain center was almost exactly north or south of a center of low pressure; group **D** contains 54 cases in which the rain was associated with an area of low pressure chiefly on its western side; group **E** contains 25 cases in which the rain was partly over an area of low pressure, and partly over an area of high pressure, being about equally divided between them; group **F** contains 22 cases in which the rain-fall was accompanied by a barometric pressure above 30 inches, and the rain area was situated between two areas of high pressure; and group **G** contains 38 cases in which the rain fell chiefly over an area of high pressure, and was not distinguished by the peculiarity of group **F**.

15. These great rain areas are found in all months of the year. The distribution by seasons is as follows: Winter, 74; Spring, 128; Summer, 78; and Autumn, 78; showing that over the North Atlantic Ocean, great rains occur most frequently in the spring of the year, especially in the month of March.

These rain areas sometimes have very great extent, there being 120 cases in which the rain area was at least 1000 English statute miles in length; 29 cases in which it was at least 1500 miles in length; 8 cases in which it was at least 2000 miles in length; and 5 cases in which the rain area was over 2500 miles in length.

The number of rain areas associated with areas of low pressure, chiefly on the eastern side (group **B**) is 161; and the number chiefly on the western side (group **D**) is 54. The former number is three times the latter. If, however, in this comparison we include group **A**, and consider half of these cases as situated on the east side of the low center, and the other half on the west side, we shall have on the east side 176 cases and on the west side 68 cases; which numbers are in the ratio of 2·6 to 1.

16. Rain, with barometric pressure somewhat above 30 inches,

is unexpectedly prevalent over the Atlantic Ocean; there being 38 cases in which the rain center was associated with a pressure above 30 inches; 17 cases in which the rain center was associated with a pressure above 30·1 inches; and 5 cases in which the rain center was associated with a pressure above 30·2 inches, the highest being 30·4 inches. There were also 25 cases (group **E**) in which the rain was about equally divided between areas of high and low pressure. Similar cases sometimes occur in the United States, where great rain areas frequently extend somewhat beyond the isobar 30 inches.

Two-thirds of the cases included in group **G** were so near to the Gulf Stream that this stream may be presumed to have had an important influence on the rain-fall. The five cases in which the rain center was associated with a pressure exceeding 30·2 inches were all near the Gulf Stream, and appear to have been similar to cases in the United States.

We see that over the Atlantic Ocean the air does not always descend from the upper regions over every part of an area of high pressure. Over some portion of an area of high pressure, the air frequently ascends; and this appears to take place when the air contains an unusual amount of aqueous vapor.

17. A comparison of the results now obtained suggests some important conclusions respecting the influence of local causes in modifying the relation of rain-fall to barometric pressure. We have found that in the United States, east of the Rocky Mountains,—

1. South of Lat. 36°, a rain-fall of 2½ inches in 8 hours at any station occurs on the east side of a low area more frequently than on the west side, in the ratio of 2·6 to 1.

2. North of Lat. 36°, a rain-fall of 2 inches in 8 hours at any station occurs on the east side of a low area more frequently than on the west side, in the ratio of 2·8 to 1.

3. A total rain-fall of 9 inches in 8 hours at all the stations east of the Rocky Mountains occurs on the east side of a low area more frequently than on the west side, in the ratio of 6·2 to 1.

4. Over the North Atlantic Ocean great rain areas occur on the east side of an area of low pressure more frequently than on the west side, in the ratio of 2·6 to 1.

5. In Europe a rain-fall of 2½ inches in 24 hours at any station occurs on the east side of a low area more frequently than on the west side, in the ratio of 2·0 to 1.

These results indicate that in the United States and Europe, as well as over the North Atlantic Ocean, great rain-falls are generally associated with a barometric pressure somewhat below the mean, and the precipitation occurs chiefly on the eastern side of a low area. We notice, however, considerable discordances which may be partly due to the different modes of comparison which have been adopted. In *No. 1* a center of low pressure was compared with the station of greatest rain-fall when the rain-fall amounted to at least 2½ inches in 8 hours. In *No. 2* a center of low pressure was compared with the station of greatest rain-fall, when the rain-fall amounted to at least 2 inches in 8 hours. In *No. 5* a center of low pressure was compared with the station of greatest rain-fall, when the rain-fall amounted to at least 2½ inches in 24 hours. In *No. 3* a center of low pressure was compared with the station of greatest rain-fall, when the total rain-fall at all the stations east of the Rocky Mountains was unusually great. In *No. 4* the amount of rain-fall is entirely unknown, but the center of a great rain area was compared with the center of a neighboring area of low pressure.

The principal discordances in the preceding results cannot be ascribed to the different modes of comparison adopted, but must be due to some other cause. The great excess of rain centers on the east side of the low center in *No. 3* may reasonably be ascribed to the influence of the Atlantic Ocean with its Gulf Stream, furnishing an inexhaustible supply of vapor; and the comparatively small number of rain centers on the east side of the low center in Europe may be ascribed to the influence of the dry air in the interior of the continent.

18. The preceding results have been derived from a comparison of rain-falls of unusual magnitude. It is not safe to conclude that the same results would be derived from a comparison of the aggregate rain-fall for an entire year at each station, since small rain-falls may be subject to a law somewhat different from those of extraordinary magnitude. There is another mode of comparison which takes account of the total rain-fall at any station. Generally on the preceding side (which is usually on the eastern side) of a low center, the barometer is falling, and on the following side (which is usually the western side) the barometer is rising. The mode of comparison consists in determining the total amount of rain which comes during a year with a falling barometer, and also that which comes with a rising barometer, and finding the ratio of these two amounts.

19. In my 12th paper I gave the results of this mode of comparison derived from the best materials which I was able to obtain. More recently I have extended the comparison to Pawlowsk near St. Petersburg; to Brussels for an entire year; to Aberdeen for two years; and I have included the observations of two years at Indianapolis, Indiana. These last observations were derived from the Signal Service, the rain being measured three times a day. The time of least pressure was

determined from the tri-daily weather maps, and the rain was accordingly distributed under the two heads of falling and rising barometer. This method cannot give accurate results, but may furnish useful information in the absence of hourly observations. By grouping together those stations which seem most intimately related, we obtain the following results, showing the ratio of the amount of precipitation which comes with a falling barometer, compared with that which comes with a rising barometer.

Indianapolis, Ind.,	ratio,	1·32 to 1
Philadelphia, Penn.,	"	2·88 to 1
Seven British stations,	"	2·08 to 1
Paris and Brussels,	"	1·19 to 1
Pawlowsk, Russia,	"	1·06 to 1
Prague and Vienna,	"	0·80 to 1

20. These results exhibit a remarkable accordance, and indicate the operation of a general cause. They are similar to those previously stated, but are much more definite. At Philadelphia the amount of rain which falls while the barometer is descending is nearly three times as great as that which falls while the barometer is rising; and during the six colder months of the year, the rain-fall in the former case is nearly five times as great as in the latter case. In summer, thunder showers frequently occur with an abundant fall of rain accompanied by a slight rise of the barometer, and at such times there is more rain with a rising than with a falling barometer. The entire Atlantic coast of the United States, North of Lat. 36°, exhibits results similar to those found for Philadelphia.

As we proceed westward from the Atlantic coast, the ratio of the precipitation when the barometer is falling, compared with that when the barometer is rising, changes somewhat rapidly, and before we reach the Mississippi River the ratio is reduced to 1·32. These results indicate that the great excess of rain on the eastern side of areas of low pressure near the Atlantic coast is due to the fact that on the eastern side they have the Gulf Stream, which furnishes an inexhaustible supply of vapor.

In Great Britain the amount of rain with a falling barometer is twice that with a rising barometer; but as we proceed eastward this ratio diminishes rapidly, and in Central Europe the precipitation is greater when the barometer is rising, than when the barometer is falling. This result is due to the fact that in Central Europe, areas of low pressure have a comparatively dry air on their eastern side, and there is a more liberal supply of vapor on the western than on the eastern side. Hence we conclude that the amount of rain-fall on the eastern side of an area of low pressure depends largely upon the direction and distance of the principal supply of aqueous vapor.

ART. XXVIII.—*The Sensitive Flame as a means of Research;* by W. LECONTE STEVENS.

A LITTLE over thirty years ago the discovery was published in this Journal* that under certain conditions a naked flame of illuminating gas may become sensitive to sonorous vibrations. Nine years elapsed before any development grew out of this acquisition to science. In 1867, Mr. W. F. Barrett, who was at that time an assistant in the laboratory of the Royal Institution, published his independent discovery of the sensitiveness of flame; and the use of the manometric flame, in the hands of Rudolph Koenig, was subsequently developed with great skill for the analysis of compound tones. The use of Professor Barrett's flame has become widely known, especially through the familiar volume of lectures on Sound by Professor Tyndall. Govi in Italy, Barry in England, and Geyer in America independently discovered the method of securing a sensitive flame, with no pressure higher than that of the ordinary street mains, by causing air to mingle with the gas after it issues from the nozzle, and allowing the mixture to burn after passing through wire gauze While this flame may be made exquisitely sensitive, it is not so convenient in practice as the high pressure flame of Professor Barrett. It is well known that these flames are usually sensitive only to sounds of high pitch, and through a limited range of pitch, this range becoming generally narrower with increase of sensitiveness. During the last few years Lord Rayleigh has used the sensitive flame with signal success in studying certain analogies between sound and light. His interesting lecture on "Diffraction of Sound," delivered a little over a year ago before the Royal Institution,† served as my starting point; and I am further indebted to him for special instructions without which I should perhaps not have succeeded in performing satisfactorily all the experiments mentioned in his lecture. As this lecture has not thus far been re-published in America, a brief resumé of it may possibly be acceptable.

Waves of light are so short that special precautions are needed to exhibit the phenomena of diffraction. Light emanating from a point and interrupted by an obstacle produces a shadow that may be regarded for all practical purposes as geometric. Waves of audible sound, on the contrary, are so long that when an obstacle is interposed the effect of diffraction masks that of radial propagation, and hence it is not usually

* On the influence of Musical Sounds upon the Flame of a jet of Coal-gas. By John LeConte. This Journal, January, 1858.

† Proceedings of the Royal Institution of Great Britain, Jan. 20, 1888.

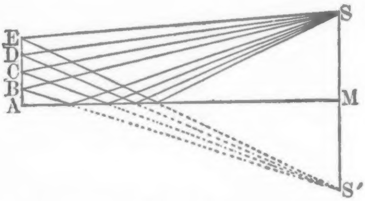
easy to make a sound shadow manifest. The difficulty in sound is not to produce diffraction but rather to limit it by using the shortest wave-lengths possible. The pitch employed by Lord Rayleigh was more than 20,000 vibrations per second, corresponding to a wave-length of less than two-thirds of an inch. To measure this the waves are reflected from a surface arranged vertically across the direction of propagation, thus producing interference with the direct waves. The position of the nodes and ventral segments is determined by moving the reflector toward or from a sensitive flame interposed between it and the source of sound. The flame flares in a ventral segment and burns quietly at a node. The distance between two points of quiescence is a half wave-length, from which the pitch is readily computed. Knowing the wave-length, if this be small in comparison with the diameter of an obstacle such as a disk, it is possible to calculate the deflection necessary for the meeting of secondary waves behind it, from its opposite edges, in order to produce a maximum or minimum of intensity. In this way, as much as eight or nine years ago, Lord Rayleigh repeated acoustically the celebrated experiment suggested by Poisson to Fresnel, and first performed by Arago, by which a bright point was found at the middle of the shadow of a small disk. Applying the formula for Huygens's zones, an acoustic diffraction grating was made by which sound was converged to a focus, as if by a lens, the flaring of the flame at this focus being very violent. Around it, according to theory, there should be several successive rings of motion and quiescence, or, in other words, of noise and silence. The first ring of noise, and the rings of silence that precede and follow it, are detected without difficulty by means of the sensitive flame.

All of these experiments by Lord Rayleigh have been repeated by me. The source of sound used is Galton's adjustable whistle, through which a blast is sent from a cylinder of compressed air or oxygen. The sensitive flame is fed from a similar cylinder of compressed coal gas, the pressure of the supply being carefully regulated in each case by means of a water manometer gauge. The whistle is capable of giving a pitch as high as 18,000 or 20,000, but as this limit is approached the intensity becomes too much diminished, and practically the best pitch it yields is about 13,000 vibrations per second. Lord Rayleigh's whistle is slightly different in construction, and probably better than the Galton whistle. But there is no difficulty in attaining good results with this pitch. The greatest practical difficulty is that of keeping the sensitiveness of the flame exactly right, the slightest variation of pressure making it inconstant, and causing it to give misleading indications when the attempt is made to apply it to purposes of measurement.

I have attempted by means of the whistle and flame to verify acoustically the experiment in light first performed by Grimaldi and analyzed by Dr. Thomas Young, that of producing diffraction bands by transmitting waves in the same phase through two small openings, and exploring the air with the sensitive flame for the hyperbolic lines of maximum and minimum motion. The whistle, giving forth waves 1·05 inch in length, was placed 34 inches from the screen of cardboard, whose width was two feet. Near the middle of this were cut two vertical slits, 3 inches apart, and each $\frac{1}{4}$ inch wide. The position required by theory for the hyperbolic bands was determined, the screen being at right angles to the direction of the whistle from its middle point. The middle line of maximum motion behind the screen was detected without difficulty. It was discontinuous, as might be expected when the wave length is so considerable in comparison with the distance between the apertures. The nearest hyperbolas on the two sides of this were found in their right position, and traced back rather more than a foot from the screen, but they were not so well defined as the middle line. The next pair of hyperbolas was also found, but with poor definition. By using slits a half-inch in width results were perhaps a little better, though in neither case could any measurements approximate to exactness.

Fresnel's celebrated experiment of producing interference bands by reflection of light from two mirrors inclined at an angle of nearly 180° was tried by Professor A. M. Mayer and myself conjointly, using sound waves. A large plate of glass was rested on the table, and another plate inclined to it at an angle of 152°, the whistle being 67 inches from the flame, 4 inches from the inclined mirror, and 13 inches above the table. Six interference bands were detected by means of the flame, their mean distance apart being 4 inches. By subsequent calculation this result was found correct to within a tenth of an inch. An important source of uncertainty, however, in this experiment arises from the waves proceeding directly from whistle to flame. Even if a screen is interposed, enough space has to be left below it to allow for the passage of sound rays reflected from the two mirrors. From the lower edge of the screen, therefore, waves are diffracted and may interfere with either or both sets of waves reflected from the mirrors. The trouble from this source caused the abandonment of this plan of experiment.

A modification of the Fresnel experiment is that of using but a single mirror, which may be rested horizontally on the table, and allowing the waves reflected from it to interfere with those radiated directly from the whistle. The effect is obviously the same as if they proceeded from two sources, but interference bands can be produced on only one side of the median line. In the accompanying diagram AM is the plane of the mirror, S the source of sound, and S′ the virtual source from which the reflected waves may be regarded as coming. Let the nozzle from which the flame issues be placed first at A and then lifted vertically. The flame will flare at the points B, C, D, etc., whose distances respectively from S and S′ differ by an even number of half wave-lengths. Midway between A



and B, B and C, etc., are points of complete interference where the flame should burn quietly. The distance AB is approximately equal to $\frac{AM}{SS'}\lambda$. The accompanying table gives a comparison between the results of theory and experiment, in which the height of the whistle above the table, MS, is 10 inches; the distance AM is 36 inches, and the wave length, λ, is 1·05 inch. The successive measurements are of distances above the table at which the flame became quiescent. The first column is calculated from the formula; the others are the records from five sets of experiments.

THEORY.	I	II	III	IV	V
·945	·8	1·0	·9	1·0	1·0
2·835	2·8	2.7	2·7	2·8	2·9
4·725	4·7	4·6	4·7	4·9	4·7
6·615	6·7	6·7	6 7	6·9	6·7
8·505	8.9	9·0	8·8	9 0	9·1
10·395	11·0	11·3	11.0	11·2	11·3
12·285	....	13·6	....	13·6	13·6

The sensitive flame is not applicable for purposes of exact measurement, as these experiments show; but it is much more nearly so than has been generally supposed. Without its aid there would have been no possibility of establishing these important analogies between light and sound.

Art. XXIX.—*The Denver Tertiary Formation*;* by Whitman Cross.

Introduction.

It is the desire of the writer to present in the following article a succinct account of a newly recognized Tertiary Formation, which, while of very limited geographical extent, yet possesses characteristics of special importance in several directions. The points of interest to be brought out may be grouped as follows:

1. The Formation in question occupies a portion of the area about the city of Denver, Colorado, hitherto assigned to the Laramie Cretaceous.

2. The conglomerates and sandstones of the Formation are chiefly made up of materials derived from a great variety of andesitic lavas of whose outpouring and destruction alike there is no other record now known.

3. The celebrated fossil-plant beds of Table Mountain, at Golden, belong to the Denver Formation,—hence the taxonomic value which has been given to this rich flora must be considered subject to revision.

4. The vertebrate remains are of individual importance and also present some very remarkable associations, which are apparently in direct conflict with all past observations.

It must be assumed in this notice that the reader is already more or less familiar with the geological structure of the belt where the stratified rocks of the Great Plains abut against the Archæan foothills of the Rocky Mountains. Especially in Colorado has this band been repeatedly studied and described in well-known publications, by members of the Hayden and of other Government surveys.

The principal feature of the region in question is a sharp folding of the sedimentary rocks, in general parallel to the line of contact with the Archæan, so that the larger streams issuing from the mountains expose in their banks more or less extensive sections of vertical or of steeply dipping strata, which soon assume a horizontal position under the plains.

At Golden, twelve miles due west of Denver, the section is, from local causes, exceptionally thin, so that the horizontal beds of Table Mountain, protected by a basalt sheet, approach to within four thousand feet of the Archæan foothills. Midway in this interval stand the vertical coal beds at the base of

* Published with the permission of the Director of the U. S. Geological Survey.

what is now commonly called the Laramie Group. Numerous fossil leaves have been obtained in these vertical coal-measure rocks, but they have been found much more abundantly in the horizontal strata of Table Mountain, and although the intervening space is largely obscured by surface deposits, the plants of the two horizons have always been treated collectively, by both geologists and palæontologists, as coming from a single Formation, however that may have been designated. Among those who have described the vicinity of Golden, with more or less detail concerning the strata under consideration, may be mentioned: John L. LeConte, F. V. Hayden, Leo Lesquereux, A. R. Marvine, C. A. White, and Lester F. Ward.*

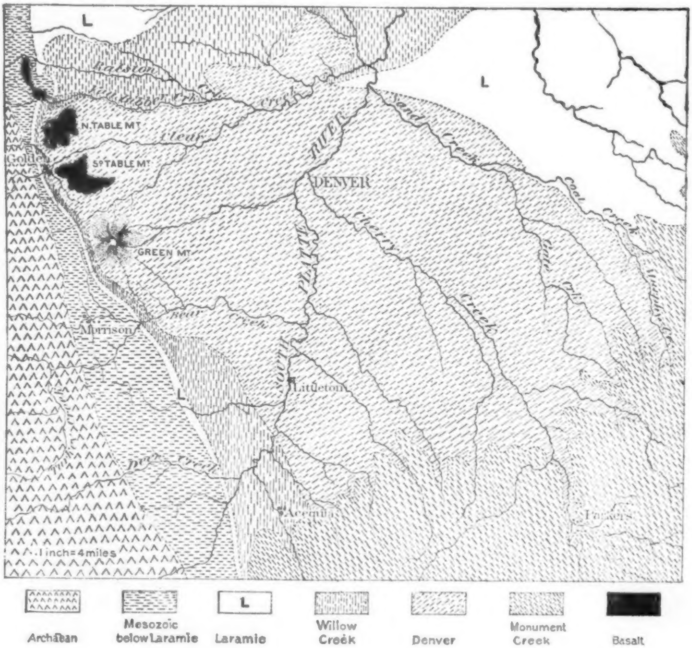
In the summer of 1881 the writer first observed that the Table Mountain strata possessed characteristics proving them to belong to a series distinct from the normal Laramie. In the course of the field-work preliminary to a report upon the geology of the Denver Coal Basin, under the direction of Mr. S. F. Emmons, of the U. S. Geological Survey, it was found that the beds of Table Mountain belonged to a series occupying a Tertiary basin extending eastward underneath and beyond the city of Denver,—whence the name here applied. It was further shown, by Mr. George H. Eldridge, my colleague in this work, that there existed another distinct Tertiary Formation between the Denver and the Laramie, provisionally called by him the "Willow Creek beds." Mr. Eldridge has moreover identified this lower Tertiary Formation even at Golden, in the gap between the coal beds and Table Mountain.

This article can only treat of the more important facts peculiar to, or best exhibited by, the beds in question, and broader or more local relationships must be left for the final report.

A preliminary statement of the most important results of this investigation was made in two papers read before the Colorado Scientific Society, July 2, 1888, by Mr. Eldridge and the writer. Aside from the identification of the two Tertiary Formations, many important observations were made by Mr.

* J. L. LeConte.—"Notes on the Geology of the Survey for the extension of the Union Pacific Railway, from Smoky Hill River, Kansas, to the Rio Grande." Phila., 1868, p. 51. F. V. Hayden.—Second Annual Report, U. S. G. & G. S., 1868, p. 135; Third Annual Report U. S. G. & G. S., 1869. p. 35; Bulletin 4, Second Series, U. S. G. & G. S., p. 215; Sixth Annual Report, U. S. G. & G. S., 1872, p. 328. Leo Lesquereux.—Monographs of the U. S. G. & G. S., vol. vii, "The Tertiary Flora," 1878; vol. viii, "The Cretaceous and Tertiary Floras," 1883. A. R. Marvine.—Seventh Annual Report, U. S. G. & G. S., 1873, pp. 109, 130. C. A. White.—Eleventh Annual Report, U. S. G. & G. S., 1877, p. 192. L. F. Ward.—"Synopsis of the Flora of the Laramie Group." Extract from the Sixth Annual Report of the Director, U. S. Geological Survey, Wash., 1886, p. 537. "Types of the Laramie Flora." Bulletin 37, U. S. Geological Survey. Wash., 1887.

Eldridge in studying the older groups. These two papers were published in full in the "Mining Industry" of Denver, July 13, 20, 27 and August 3 and 10, 1888. The monograph on the Denver Coal Basin, by Mr. S. F. Emmons, is now in preparation.



I. Description of the Formation.

The area occupied.—By reference to the accompanying map the surface distribution of the Denver beds may be readily seen. Upon that map the eastern limit of the Archæan rocks marks the line of the foot-hills. In the narrow zone between the Archæan and the Denver area are the upturned strata of the Trias, Jura, Cretaceous, and the Willow Creek Tertiary.

The area of Denver beds represented is somewhat less than 400 square miles. Its western boundary is determined by the upturning of the strata along the great fold and by the subsequent erosion. On the north and northeast the line apparently expresses the original limitations of the basin at this level. To the south and southeast the Denver beds disappear under the horizontal strata of the Monument Creek Tertiary, which are unconformable with all earlier deposits. What the extent of the Denver beds may be in this direction is now unknown, but it is probably not great, for the larger part of the Formation was destroyed prior to the deposition of the Monument Creek.

The important exposures.—The only strata belonging to the Denver beds which are particularly mentioned by earlier investigators are in Table Mountain, at Golden, and while these are truly typical of the Formation their stratigraphical relations are there certainly obscure. In the course of the present work hundreds of out-crops were studied, scattered over the entire area, in the banks of streams, of ditches, and in numerous railroad cuttings. The outcrops of the plains must, however, be interpreted in the light of the more extensive exposures of Table and Green Mountains. In South Table Mountain the lower third of the series is best shown, while one must go to the neighboring Green Mountain for all the higher strata and for a clear exhibition of the stratigraphical relations of the whole.

Green Mountain lies upon the western border of the plains, midway between Golden and Morrison (see map), and is so related to the great fold that the strata at its western base are in vertical position while those of the summit are horizontal, and upon the slope between these points the fold thus indicated is clearly shown. The "mountain" is a bald massive hill, of smooth and gentle slopes, rising 1000 feet above the eastern base, with long rounded ridges on all side but the west. Probably the absence of projecting outcrops explains why it has received so little attention from those who have repeatedly visited Table Mountain.

On the western face of Green Mountain, opposite the summit, upon a minor ridge and in a small ravine below it, is a practically continuous outcrop extending from near the summit down to the base of the steeper slope. Owing to the fold, mentioned above, 900 feet of strata are here exposed in a vertical distance of 500 feet. *These 900 feet of Denver beds are not elsewhere preserved.* At the bottom of this section is a very marked dark conglomerate dipping 45° eastward. The 500 feet of fine-grained Denver strata below this conglomerate are but poorly exposed near Green Mountain. They occupy a narrow band between a definite horizon of the Willow Creek beds and the dark conglomerate at the base of the described outcrop.

A second outcrop of great importance is at the southwestern base of Green Mountain, where a ravine cuts diagonally across vertical strata, giving a continuous section from the base of the Denver beds, which is clearly shown, down through the entire thickness of the Willow Creek and Laramie Formations, ending with the coal-bearing basal sandstone of the latter. From this ravine the coal horizon and the characteristic conglomerate of the Willow Creek beds may be traced far in either direction.

These two important outcrops do not seem to have been seen by any of those persons who have previously described this district, yet they contain the keys to the stratigraphy, without which the latter cannot be correctly interpreted.

The numerous outcrops of South Table Mountain, which do not need to be specified, supplement those of Green Mountain to a great degree. Here the peculiar constitution of the Denver beds may be conveniently studied in detail, though the well-preserved fossil leaves which they contain have hitherto received exclusive attention.

Clear Creek has not cut quite deep enough at Golden to reveal the actual base of the Denver beds. This horizon therefore continues westward from Table Mountain until brought to the surface by the great fold. It is only clearly shown at a point west of the State Reform School, in an old railroad cutting which also discloses the Willow Creek conglomerate.

Mechanical constitution.—The section of the Denver strata consists of two very distinct parts, both as regards texture and composition. By careful measurements projected upon a profile line surveyed across Green Mountain, the total thickness of Denver beds there represented is estimated to be 1440 feet. Of this series the upper 525 feet are mainly made up of very coarse conglomerates while the lower 915 feet are as a rule fine-grained strata. The coarse conglomerates and the upper half of the finer-grained beds are preserved only in Green Mountain.

A detailed section of the Denver beds is of little general value because variability in make-up is the preëminent characteristic of the finer-grained division. Yellowish brown friable sandstones prevail, with all manner of gradations into clays or into conglomerates. The transitions appear both laterally and vertically so that it becomes difficult or even impossible to closely correlate strata of isolated exposures occurring at the same general horizon. The conglomerates of the lower division are especially liable to variation, and few of them appear to have more than a local development, yet they are prominent features of almost any extensive outcrop. Few pebbles in these conglomerates exceed three inches in diameter. Cross-bedding and local unconformity between beds of sharply differing constitution are further features of common occurrence.

The heavy conglomerates of the upper division will be referred to later on.

Materials of the Denver strata.—The peculiar composition of the Denver beds was first observed in the dark conglomerates of Table Mountain, which contain only pebbles of andesitic rocks, some porous and some compact. The sandy matrix is merely finer material of the same character and the cementing substance is usually some zeolite (heulandite, stilbite, chabazite, etc.) or yellow calcite. Microscopical examination of the sands and of the sand grains in the clays reveals only particles which, so far as they can be identified, are like the constituents of the andesites seen in pebbles. Augite grains or rough crystals containing glass-inclusions and other characteristic interpositions; plagioclase, hornblende and biotite, with the peculiarities noticed in these minerals as components of the andesites; dull reddish brown grains with imbedded crystals, which clearly represent particles of the andesite rocks more or less decomposed,—all these are found, *the only recognizable mineral constituents of Table Mountain sandstones and clays.*

At the base of the main Green Mountain exposure which has been mentioned is a dark conglomerate, about 25 feet in thickness, dipping 45° eastward. This bed is probably at the horizon—also exhibiting a marked conglomerate—a few feet below the basalt cap of Table Mountain. While tracing out and studying this horizon in Green Mountain three Archæan pebbles were seen,—all others being eruptive and apparently all andesites. The average diameter of the pebbles in this bed is from two to three inches.

Above this conglomerate appear again fine grained sands and clays in an estimated thickness of 285 feet, in which there is no strongly developed pebble bed, though sand layers greatly predominate over clays. This series is like the lower one, almost exclusively made up of andesitic debris.

The fine-grained sediments are abruptly succeeded by a series of very coarse conglomerates or bowlder beds of an estimated thickness of 525 feet. In the first of these coarser beds the pebbles range in size from a diameter of two feet downward, and while eruptive rocks largely predominate there are many of granite or of gneiss and a few of red and white sandstone. The gravelly matrix is largely made up of angular quartz and feldspar grains. A return to fine-grained sediments is quickly followed by bowlder beds which continue to the top of Green Mountain, the average size of the bowlders gradually increasing upward in the series while the amount of eruptive material rapidly decreases and becomes at last quite subordinate. Bowlders of various sedimentary rocks are numerous in these beds, the characteristic Dakota conglomerate being perhaps most prominent among them.

The Denver strata of the plains belong to horizons represented in Table Mountain, i. e., to the lower third of the Formation. A study of numerous exposures shows that the remarkable freedom from non-eruptive materials characterizing the Table Mountain beds does not strictly hold for these equivalent strata. Along the Platte River and to the eastward one can generally detect a small amount of quartz or of red feldspar (microcline) in the more sandy Denver beds, though these substances are lacking in many places, even along Coal Creek, farthest from the foothills. Quartz and red microcline are taken as representing Archæan rocks, directly or indirectly They become prominent in the Denver beds of the plains area only locally and under circumstances which will be considered in another part of this article. As a result of their composition the finer-grained Denver rocks are easily recognizable when one is at all familiar with them. They possess a dull reddish brown color, and while friable and crumbling they resist degrading agencies in a manner peculiar to them. This is due to the admixture of clay with most sands, and to the development of a zeolitic cementing substance derived from the andesite. Tests show that as high as 50 per cent. of some sandy strata are soluble in hydrochloric acid with production of gelatinous silica.

Fossils.—The fossil flora of Table Mountain has been referred to. It is one of the richest yet discovered and has been very fully described. As one of the earliest discoveries in the west it has been an important element in discussing the floras found more recently in other formations. During the present work fossil plants were observed in many places and some collections were made, but so far few species have been found which were not already known in Table Mountain. Good localities might be developed in various places over the entire field.

A very few invertebrate fossils have been found in plant-bearing Denver beds, but they are not of much determinative value.

By far the most important, as well as the most interesting fossils of the Denver beds are the large bones found in several places, which are provisionally referred by Prof. O. C. Marsh to various Cretaceous types of the Dinosauria. A single fossil from the west bank of the Platte River, near Denver, has been described by Prof. Marsh as a new species of *Bison*, and a probable Pliocene age ascribed to the beds containing it.

A consideration of the evidence afforded by these various groups of fossils as bearing upon the age of the Denver Formation shows that these different elements are in conflict with each other and with the stratigraphy. This fact renders necessary an examination as to the relative values to be given to these conflicting evidences. Some results of this examination will be given in the succeeding sections of this article.

II. The Age of the Denver Formation.

Having given a description of the Denver beds and of their occurrence, there arises the problem as to their geological age,—a problem involving in its own solution that of several others of far greater importance. The evidences to be given touching the age of these beds are very conflicting and are plainly not to be brought into harmony until certain elements of that evidence have been subjected to renewed examination by competent hands. It is hoped that the necessity for this revision will be plain from the following discussion.

There are certain facts of primary importance which have been brought out during this investigation, and these facts must be regarded in all future discussions. From these facts certain apparently logical deductions may be drawn, which should be accepted unless the logic is proven faulty.

a. Stratigraphical evidence.

The Denver beds lie between two distinct Formations and the relations to each are definitely known. The upper Formation is of recognized Tertiary age,—the Monument Creek; the lower is the newly recognized Willow Creek Formation, which will be briefly described by some extracts from the article by Mr. Eldridge, which has already been cited.

Description of Willow Creek beds.—"The Formation next succeeding the Laramie in geological order and unconformably resting upon it is the lower of the three Tertiaries that occur in the Denver field, for which the name "Willow Creek" is here suggested, from the locality in the southern part of the field, from one to three miles southeast of the mouth of the Platte Cañon, where it has its greatest and most typical development. It is composed of a basal member of conglomerate or gritty sandstone, according to its distance from the foothills, with an overlying zone of gray, argillaceous or arenaceous shales containing lenticular masses of hard, quartzose sandstone, with an occasional ironstone. Where confined between under-and-over-lying groups, it has a thickness varying between 600 and 1200 feet.

"The conglomerate at its base has a thickness over the greater portion of the field of about 200 feet, though this may become the bulk of the formation, as in its type locality, or may decrease to the merest edge as at its northern limit, along the Platte River, near Brighton. It is extremely characteristic, containing as it does pebbles derived not only from every formation that lies below it in the Denver field, but also from others lying far beyond, especially the Carboniferous, of which the debris affords some excellent specimens of *Beaumontia*, a case parallel to that of the occurrence of Silurian pebbles in the Dakota. Like the pebbles of the Dakota, too, only in a far greater degree, those of this formation have undergone extreme silicification. Jaspers, agates, flints and silicified wood abound, and the debris of the older groups, including the fossiliferous limestone just noted, has often undergone the most complete alteration in this manner. This feature, however, is especially noticeable only in that portion of the formation which, from having been laid down within a comparatively short distance of what was probably the ancient shore line, contains a very large amount of pebbles of the older rocks, and is thus best calculated to show any changes of this kind that may have occurred."

Relation of the Denver to the Willow Creek.—The Denver beds occupy a basin eroded out of the Willow Creek, in the greater part of the area now under discussion. There is thus a general non-conformity between the two deposits, while the details of this relationship may be seen in certain places.

Though the actual contact line of the two Formations is seldom seen, owing to the friable nature of the strata and the prevalence of surface deposits, there is no difficulty in assigning isolated outcrops to the proper series, on lithological grounds which have been explained. The interval between the Denver and Willow Creek epochs will be spoken of in a succeeding section.

Relation of the Denver to the Monument Creek.—As has been stated in the descriptive part, about two thirds of the known thickness of the Denver beds were removed prior to the deposition of the Monument Creek Formation. There is, moreover, no reason to suppose that the upper strata of Green Mountain represent the actual top of the Denver beds, nor can we now determine the former lateral extent of the Formation.

Concerning the length of the time interval between Denver and Monument Creek deposits we have no data.

b. Lithological evidence.

The materials of the Denver beds.—It is a fact of general experience that quartz is usually the most abundant mineral in strata which are made up of the worn debris of older rocks. This position comes to the quartz largely by reason of its superior hardness and the absence of cleavage, properties enabling it to resist attrition better than the other common rock-making minerals. When detritus from areas of the crystalline schists has been the chief element in making up the sediments of adjacent oceans or seas, the relative amount of quartz in the strata formed will depend upon the violence of the destructive agencies and upon the rate and conditions of deposition. Abrasion and attrition or conditions favoring chemical decomposition will destroy the accompanying minerals more rapidly than the quartz and will hence tend to increase the proportion of the latter in resulting sandstones.

These generalizations are illustrated in all the groups of sedimentary formations known at the eastern base of the Mountains, from the Cambrian up to the Denver beds. The fine grained Dakota and Laramie sandstones are almost exclusively made up of quartz. In the Willow Creek grits and sandstones appears a variety of materials mentioned by Mr. Eldridge in the statement already given.

In view of the facts just considered the sudden and almost complete change in constitution which is met with in the Denver beds is certainly worth more than a passing notice. Instead of minerals and rocks derived either directly or indirectly from Archæan sources there is found material resulting from the degradation of a great series of eruptive rocks. It is a fact of much significance too, that for 900 feet of thickness the Denver beds are very fine grained, having been slowly deposited under conditions which have usually brought quartz into relative prominence.

The andesites represented by pebbles and bowlders in the Denver strata are of many different types and the name must be used in its widest sense to cover them. Hornblende or augite-andesites of rather basic composition are the most common types, but more acid varieties, carrying quartz or tridymite, with biotite, are numerous, while at the opposite extreme are hypersthene-bearing andesites of characteristic features. Only andesites have thus far been identified.

There is a variation in texture and structure shown by these andesites which is almost as marked as that in composition:—some are vesicular, many are porphyritic, and others are compact and fine-grained. In the development and in the mutual relations of the mineral constituents of these andesites one accustomed to studying the microscopical physiography of eruptive rocks will see abundant proof of their extrusive character. Some of the denser beds of Table Mountain seem composed of volcanic ashes or of small angular grains belonging to a single rock type. Such material may be called tufa, but the sandstones containing worn particles of various kinds are largely predominant.

It has already been stated that there is some quartz in the sandy strata of the plains and that great bowlders of Archæan and of sedimentary rocks are found in the upper division of the Denver beds.

The sources of materials.—The nature of the rock and mineral substances composing the Denver beds having been stated, it remains to consider their origin in order that the full value of this evidence may be appreciated. Attention is first called to the eruptive rocks, as the predominant material.

The first point in evidence is negative. *There is no known source which can be assigned with plausibility for any one of the many andesitic types represented in the Denver strata.* No andesite masses are known in the mountainous area to the westward as far as the continental divide, though it is admitted that they may exist in local development. The more distant andesitic masses in Middle or South Park cannot be considered, nor a hypothetical transient volcanic vent in the plains area, for neither of these explanations can meet the facts of observation. The problem is a double one, viz: to account for the exclusion of the common materials (quartz, etc.) simultaneously with the appearance of the unusual, and this in a basin adjacent to a mountainous Archæan district.

These considerations have determined the form of the solution to be offered. *The andesitic masses which furnished the materials for the lower part of the Denver sediments were so situated as to effectually prevent the access of all Archæan and sedimentary debris to the lake of that epoch.* That is to say, in the interval between the Willow Creek and Denver epochs there was an outpouring of andesitic lavas completely covering the Archæan and sedimentary rocks of the area afterwards contiguous to the Denver lake. When sedimentation began again only eruptive debris could appear in the deposits until erosion and general degradation had laid bare, here and there, small areas of granite, of gneiss or of sandstone.

The Denver strata contain the record of the destruction of a great series of allied lavas. The nine hundred feet of fine-grained sediments represent a vastly greater amount of rock destroyed, and in the series of coarse bowlder beds is evidence of the practical completion of this work. Then came a return to the surface conditions existing during the Willow Creek epoch.

The other materials of the Denver beds are easily accounted for. In the coarse bowlder beds of Green Mountain both Archæan and earlier sedimentary rocks are very prominent. They were undoubtedly derived from the adjacent western shore after the andesitic covering had been worn through.

A different origin is indicated for the quartz and red feldspar material in the fine-grained strata of the plains. Experience shows these substances to be very local in development and to be most abundant adjoining the northern and southern Willow Creek shore-lines, which were in great degree made up of friable or soft grits and sandstones. The absence of the quartz in strata nearest the mountains shows that it could not have come from that direction.

c. The Fossil Flora.

The Golden fossil flora has been fully described and repeatedly discussed in its bearing upon the age of the Laramie formation. Inasmuch, however, as some of the plants came from acknowledged Laramie and others from the Denver strata of Table Mountain, while all have been uniformly referred to the former group, through ignorance of the facts here presented, it seems plain that this fossil evidence cannot be used as a whole in discussing the age either of the Laramie or of the Denver beds. An examination as to the distribution of species in view of new evidence is naturally a matter for the palæobotanist to undertake, but it seems advisable to call attention in this place to certain facts concerning the past discussions of these fossil plants and to their present condition.

The Golden flora as described by Lesquereux.—By far the greater number of the plant remains from Golden have been described by Prof. Leo Lesquereux, originally in the annual reports of the Hayden Survey and afterwards in revised form in the previously cited monograph, "The Tertiary Flora." A few additional species were described in the later monograph, "The Cretaceous and Tertiary Floras." In the former work 95 species from Golden are described, and in the latter 8 others, making a total of 103 species and varieties from this locality.

In the following discussion two varieties of *Ficus planicostata* Lx., are omitted, as is likewise the Cycad species, *Zamiostrobus mirabilis* Lx., the single specimen of which is stated by Lesquereux to have been "found by Dr. F. V. Hayden on the surface soil without connection to any stratum of rock."* Deducting these three there remain just 100 species of fossil plants to be considered, hence many of the numbers to be given express *percentages* of the Golden fossil flora as described by Lesquereux.

An examination of the monographs cited shows that 81 species were originally described by Lesquereux; 59 species are known in the United States only at Golden,—52 of these being new species.

As to the exact geological horizons of the species; three per cent only are definitely stated, under the heading "Habitat," to come from the known coal-measure sandstones, while 13 per cent are said to come from Table Mountain. Through incidental statements as to the horizon it seems plain that 9 per cent came from the acknowledged Laramie and 16 per cent from Table Mountain

* "Tertiary Flora," p. 71.

strata. The writer cannot find any statements from which the horizons of the remaining 75 per cent of the Golden fossil plants can safely be assumed. Forty new species found only at Golden are not assigned to definite horizons.

The original specimens described by Lesquereux have been sent to the U. S. National Museum, where, through the courtesy of Prof. Lester F. Ward, Curator-in-charge of fossil plants, they have been examined by the writer within the past year. The following statements are made with Prof. Ward's permission:

Only 79 species of the Lesquereux collection from Golden could be found, the remainder being temporarily lost sight of in the confusion naturally attending the rapid growth of the Museum in such limited space. The specimens bear numbers, but there are very few labels giving localities, and the Museum catalogue contains no details, the locality "Golden, Colorado," standing for all alike.

Under the circumstances the lithological characteristics of the matrix containing the fossils is the only available means of determining the horizons from which they were obtained. The peculiar yellowish brown sandstones of Table Mountain are clearly distinguishable from the quartzose sandstone of the coal horizon, to anyone acquainted with the rocks, and the following result of an examination as to the matrix is satisfactory to the writer, though it may not be equally so to others.

Of 79 species found, 18 occur in what is judged to be Laramie sandstone or shale, and 59 in distinct Denver beds of Table Mountain, while 7 occur in both rocks, and 9 cases are in doubt. Lesquereux gives horizons for 6 species which were not found. By combining the two sources of information we get probable indications of horizon for 76 per cent of the Golden fossil plants; 22 per cent came from true Laramie strata and 63 per cent from Table Mountain beds; 9 per cent occurring in both formations.*

* After this article was completed the writer received a pamphlet by Prof. Lesquereux entitled:—"Fossil plants collected at Golden. Colorado." (Bulletin 3, vol. xvi, Museum of Comparative Zoölogy at Harvard College, Dec., 1888.) This paper (written in 1884) describes the Golden plants in the Museum at Cambridge, Mass. "They represent 118 species, or vegetable forms considered as species, 28 of which are admitted as new species, ... and 32 as new for the Flora of the Laramie Group, but known from other localities, making therefore for that Flora an addition of 60 species." There is in this paper no mention of a definite horizon or of an exact locality for a single species beyond the statement that they were collected at Golden and came from the Laramie. Prof. Arthur Lakes of Golden, who collected these specimens, has informed the present writer, upon inquiry, that he thinks the plants were all obtained from Table Mountain or Green Mountain, and that "none of them came from the proximity of the lower Coal Measures." If this is true all of these sixty species belong to the Flora of the Denver Formation, and not to the Laramie, as far as known. It is probable that more than sixty of the species from Golden, described by Lesquereux in the "Tertiary Flora" are likewise unknown, as yet, in true Laramie strata.

The work of Professor Ward.—The only recent descriptions of fossil plants from Golden are by Professor Lester F. Ward, who visited Golden in the summer of 1881, before any question as to the horizon of the Table Mountain strata had arisen. In the winter of 1882–83, however, Mr. S. F. Emmons submitted a number of fossil plants from the Denver field to Professor Ward, pointing out the lithological difference between the strata of Table Mountain and those of the Laramie proper, and stating that this marked characteristic was thought to indicate a probable Tertiary age for the former rocks. Professor Ward was requested to examine these specimens as well as his own collections at Golden, with reference to the possibility of distinguishing the two horizons by their plant remains. In an official letter to Mr. Emmons, of date of March 5, 1883, Professor Ward states his inability from the specimens at his disposal to make any important distinctions between the plants of the two horizons.

In his "Types of the Laramie Flora" (of date 1887) Professor Ward gives descriptions (with figures) of but five species from this district. The Denver strata containing plants are called "tufa;" the Laramie, "white sandstone;" but no further reference is made to this distinction. One species, *Ficus Crossii* Ward, came from the Laramie sandstone just below the coal horizon; *Ficus spectabilis* was found in Denver beds dipping 30° eastward, just south of the town of Golden; *Ficus irregularis* and *Berchemia multinervis* came from South Table Mountain; *Cornus Emmonsii* Ward, was found in the city of Denver, and is incorrectly accredited to Golden by Professor Ward. Four of the figured specimens are from Denver beds and but one from the Laramie proper.

Professor Ward's paper, "A Synopsis of the Flora of the Laramie Group" (1886), contains an elaborate table of distribution of Senonian, Laramie and Eocene plants; a discussion of this table; and descriptions of new collections of Laramie plants. In the table of distribution 323 Laramie species are enumerated. Of these, 103 occur at Golden, this flora as described by Lesquereux being inserted with a few omissions.

While describing his own collections, Professor Ward says that "the geology of Golden is very complicated,"* and he increases this complication by introducing a remarkable hypothetical fault,† between Table Mountain and the coal horizon, to explain the proximity of horizontal to vertical strata, in what he treats as a single Formation. Aside from the statement that the sandstone of South Table Mountain is "commonly called tufa"‡ Professor Ward does not, in either of the publications

* "Synopsis," etc., p. 537. † Ibid., p. 538. ‡ Ibid., p. 538.

cited, hint at any peculiarity of the Table Mountain strata, nor does he intimate in any way that they have been or might be regarded by any one as belonging to a series different from the coal-measure beds.

d. The Invertebrate Fossils.

A few invertebrate fossils have been found in the Denver beds, all of them coming from a ravine by St. Luke's Hospital, Highland (a suburb of Denver), where they were found by Mr. T. W. Stanton, in association with fossil leaves and a small tooth of a crocodile. The shells were submitted to Dr. C. A. White, of the U. S. Geological Survey, for determination, who reports as follows concerning them:

"The invertebrate fossils which have been collected from the Denver Formation comprise five species. One of them is a *Unio*, and another is a *Physa*, both too imperfect for specific determination. Another is apparently a *Corbicula*. The other two I have recognized as *Viviparus trochiformis* and *Goniobasis tenuicarinata*, respectively, of Meek and Hayden.

"If these fossils had been submitted to me without any statement of correlated facts, I should have hardly hesitated to assign them to the Laramie Group, because the two last named species are common and widely distributed in that Group and forms similar to the other three are common in that Formation also.

"That *Viviparus trochiformis* and *Goniobasis tenuicarinata* may have survived from the Laramie epoch into that of the Denver Formation is not at all improbable, especially in view of the fact that I found both those species in Utah to have passed up from the Laramie into the Eocene Wahsatch Group.

"The *Unio* and *Physa* are such forms as one might naturally expect to find in such a deposit as is the Denver Formation, which was presumably a purely fresh-water one. In such a deposit, however, one would hardly expect to find a *Corbicula*, but I am not aware of any reason why we may not assume that one of the many forms of that genus which are found in the Laramie Group survived to the Denver epoch in company with the two species mentioned.

"In short, I do not regard these invertebrate fossils as necessarily presenting any evidence against your conclusion that the Denver is a separate Formation from the Laramie."

e. The Vertebrate Fossils.

A number of isolated fossil bones have been found, both in the Willow Creek and in the Denver beds. These have been placed in the hands of Professor O. C. Marsh for identification and description. The fossils have proven very interesting and have raised a number of important problems, for the solution of which the material now available is in many ways inadequate. But there are certain phases of these problems which can be discussed now as well as at any other time.

Professor Marsh recognizes among the bones sent him various parts of the skeletons of turtles, crocodiles, dinosaurs, and of a bison. Specific determinations have not yet been made except in the case of the bison, but the numerous dinosaurian bones clearly indicate the presence of representatives of several types within this order of extinct reptiles. Until the recent discovery of "a new family of horned Dinosauria from the Cretaceous" in Montana,* Professor Marsh was inclined to assign some of the bones from the Denver area to types hitherto known in this country only in the Jura, while other remains seemed to belong to Cretaceous forms. He now considers it probable that some of the Dinosaur bones collected by Mr. Eldridge may be referable to the new family, the Ceratopsidæ.†

It is plain that the occurrence of these various animals in strata later than the Laramie introduces a very puzzling element into the discussion, and the first thing is to prove that they actually belong to the formation in question. The extinction of the Dinosauria in the Cretaceous period has been a doctrine seldom questioned by any authority. If the Dinosaur bones of the Denver beds do not belong there they must have been transported from some earlier formation, and, although unable to conceive of any method by which this transfer could have been accomplished, consistent with the other factors in the case, the writer has been slow in coming to the belief that the Dinosaurian life continued into the Denver epoch. In the paper read before the Colorado Scientific Society, in July last, I stated that it seemed most probable that these Dinosaur bones had been transported from Jurassic or Cretaceous strata to their present resting-place. This opinion has now been entirely changed, and it is firmly believed that the bones found in the Denver beds belong to animals that lived in the epoch in which those beds were deposited. A few facts in support of this belief will be given.

Science is indebted to Mr. George L. Cannon, Jr., of Denver, for several interesting discoveries, the results of a zealous detailed study of the vicinity of the city, continued for a number of years. The greater share of Dinosaurian bones thus far known from the Denver beds have been found by him. In an article read before the Colorado Scientific Society, in October,

* This Journal, Dec., 1888, p. 477. † Loc. cit., p. 478.

1888,* Mr. Cannon gave a review of the circumstances attending the finding of all Dinosaur bones known to that time in the Denver beds, and drew the conclusion that they must belong to the horizon in which they were found.

The majority of the bones thus far secured were apparently isolated, no adjacent parts of a skeleton being found together, though different parts of the animal are represented. The finds thus indicate skeletons which have been dismembered and the various parts separated, though not very widely. Bones found imbeded in Denver sandstones are never worn, the articulations of ribs and leg bones are sometimes perfect, and delicate surface sculpturing uninjured. The bone matter is soft and could not have withstood transportation under ordinary circumstances. In the strata containing the bones are no pebbles of earlier sedimentary formations, and any agency which could have transported the bones uninjured would have left traces of the rocks from which the bones were derived. The present softness of the bones is not due to decomposition; on the contrary, the original bone substance seems to be well preserved, for analysis shows eighty per cent of lime, phosphoric acid, and fluorine, in a typical specimen of bone material. It is also observed that fragments washed out of the Denver strata and now found lying in small gullies have been very much worn, even when carried but a few yards.

In the article cited Mr. Cannon also mentioned the finding of various fragments apparently belonging to one animal, in strata of South Table Mountain. He further stated that a number of bones belonging to an herbivorous Dinosaur had been obtained on the eastern slope of Green Mountain within a small area.

On January 7, 1889, Mr. Cannon gave a preliminary account before the Colorado Scientific Society of a quantity of large bones recently exposed by a cloud burst on Green Mountain at the spot where the before-mentioned bones were found. All these bones seem to belong to a large Dinosaur.

These later finds confirm the conclusions reached by study of the isolated bones. Until the new material has been studied by Prof. Marsh the full import of the discovery cannot be known, but it makes it clear that Dinosaurs lived in the Denver epoch.

Discussion of Evidence.

The strata here assigned to the Denver Formation have hitherto been considered as typical Laramie, but solely on account of their plant remains. No other evidence has been

* The Mining Industry, Denver, Nov. 9, 1888.

advanced for referring the horizontal strata of Table Mountain to the same formation with the vertical coal-measure rocks.

Both the Willow Creek and the Denver series lie between undisputed Laramie and a Tertiary Formation, which, though not yet closely studied, has been referred without question to the Miocene. The previous classification of the beds, and the fact that the fossils with a single exception are said to indicate or to require a reference to the Cretaceous, make the first problem to be considered, as follows: Do the Willow Creek and Denver Formations belong to the Laramie Group, or are they of later age?

The character of the evidence in the case has been submitted. The Denver beds are apparently separated from the acknowledged Laramie by a series of intermediate beds with important characteristics, which are visibly unconformable with the Laramie, as are the Denver beds, in turn, with the intermediate Willow Creek. But local unconformities, even greater than the angular ones here seen, may well exist with a great Group like the Laramie, and it is necessary to consider these unconformities in the light of the lithological evidence, before their real significance can be appreciated.

The Willow Creek conglomerate shows pebbles "derived from every Formation below it in the Denver field," and the unconformity here recorded was therefore not a local one within the Laramie, but extended down through almost the entire Mesozoic section. To explain this requires the assumption of a great folding of the strata adjacent to the foothills in the interval preceding the Willow Creek. In a similar manner the materials of the Denver beds testify positively to a period of great volcanic activity in the interval between the Denver and the Willow Creek epochs.

These are the facts of primary importance and the only question which can be raised is as to their interpretation. Whatever fossils have been, or may in future be, found in the Denver strata, the significance of these primary facts cannot be ignored. The claim that the Denver beds are Laramie involves the claim that the events indicated above took place within the Laramie time.

It seems to the writer that if stratigraphy and lithology can give grounds for drawing boundary lines the evidence submitted warrants the separation of the Denver and of the Willow Creek beds from the Laramie, and their reference to the Tertiary.

Above the Denver beds, and unconformable with them, as has been shown, comes the Monument Creek Formation. Hayden gave this name, in 1859, to "a series of variegated sands and arenaceous clays, nearly horizontal, resting on the upturned edges of the older rocks "* and situated on the divide between the waters of the South Platte and of the Arkansas rivers. The strata abut against the Archæan near Palmer Lake (on the Denver and Rio Grande R. R.) and extend out upon the plains an unknown distance. Hayden referred them provisionally to the Miocene, without definite data. Cope subsequently sought for fossils in these beds and as a result is inclined to confirm the assignment of Hayden. Remains of an *Oreodon* type are thought to prove an age later than the Eocene, while the occurrence of *Megaceratops Coloradoensis* indicates pre-Pliocene age.†

The strata here referred to the Monument Creek are plainly connected with the ones originally described by Hayden and no further evidence as to their age can be given.

It is clear that the Monument Creek beds are much later than the Denver beds. The latter have been folded into a vertical position along the line between Golden and Green Mountain, but the Monument Creek strata, as noticed by Hayden,‡ pass to a contact with the Archæan and are but slightly inclined (5°–15°), showing that the interval between the Denver and Monument Creek epochs witnessed important orographical changes. Two-thirds of the Denver beds in the area studied were removed during the interval.

Were it not for the presence of the fossil described by Prof. Marsh as *Bison alticornis*,§ the whole weight of evidence would be in favor of assigning the Willow Creek and Denver Formations—assuming that they are post-Laramie—to the earliest Tertiary possible. On account of this fossil, however, Prof. Marsh has stated that the strata containing it are "probably late Pliocene." But the bison specimen figured by Prof. Marsh was dug out of solid typical Denver sandstone at the same general horizon which has yielded all the other Denver vertebrates yet found. This conflict of evidence is not yet explained.

The preceding discussion has been confined to the evidence gathered in the district studied. A few more general considerations may now be brought out in conclusion.

It can scarcely be said that the reference of the Denver and Willow Creek Formations to the Eocene is opposed to the general doctrines concerning the succession of geologic events at the close of the Mesozoic. The reference is rather in full harmony with those doctrines, for they assume great disturbances at this time, causing nonconformities when sedimenta-

* Annual Report for 1869, pp. 39-42.
† Ann. Rep. U. S. G. & G. S., 1873, p. 430.
‡ Bull. 3, 2d Ser. U. S. G. S. of Ter., 1875, p. 210.
§ Am. Journ. Sci., Oct., 1887, p. 324.

tion began again and volcanic outbreaks are frequently mentioned as characterizing the beginning of the Tertiary Era.

As to the fossil flora, it is well known that Lesquereux and others have referred the entire Laramie Group to the Eocene, or Miocene, from the evidence of fossil plants. It remains a task for competent hands to ascertain whether the Table Mountain plants have influenced opinions as to what constitutes the "typical Laramie Flora," or not,—and to what extent.

The few invertebrate fossils of the Denver beds are declared by Dr. White to have no positive weight against the conclusion adopted.

As to the vertebrate fossils of the Denver strata the Dinosaurian remains certainly present an element of evidence, which, judged by current belief, is strongly opposed to the idea of a Tertiary age for the Formation. The doctrine that the Dinosauria became extinct in the Cretaceous period is generally accepted, yet it has been characterized as a "dogma" by Heer and Lesquereux.* How far is this doctrine supported by a knowledge of the actual conditions which led to the supposed extinction of this interesting group of peculiar animals? Are the facts of experience competent to establish the extinction at the time mentioned, independently of a knowledge of conditions?

The best record of accomplished extinction of the Dinosauria is found in the absence of their remains in the great Eocene Formations of the basin area west of the Rocky Mountains. The causes of this extinction are not as yet known. As Dr. C. A. White pointed out some years ago, "The climate and other physical conditions which were essential to the existence of the Dinosaurians of the Laramie period having evidently been continued into the Tertiary epochs that are represented by the Wasatch, Green River and Bridger Groups, they might, doubtless, have continued their existence through those epochs as well as through the Laramie period but for the irruption of the mammalian hordes to which they probably soon succumbed in the unequal struggle for existence."† That a group of animals with such highly specialized characteristics as are possessed by the Dinosauria could not adapt themselves to sudden changes of environment is no doubt true, but it is an assumption that the orographic movements causing or following the close of the Laramie produced sudden changes of more than local influence. In the Denver strata, whatever their age, is the proof that certain types of Dinosauria did survive the changes of conditions attending a period of folding and another period of great volcanic activity.

* Heer quoted by Lesquereux in "Cretaceous and Tertiary Floras," p. 112.
† Bull. U. S. G. and G. S., vol. iv, No. 4, p. 876.

The geological record of events in Eocene time is very imperfect, especially for the area on the eastern slope of the Rocky Mountains. Even in the Great Basin area the lowest recognized Eocene, the Wasatch, is found to contain a peculiar group of mammals (Coryphodon) and the record contains nothing concerning the development of this type. This argument may well close with the simple suggestion, offered as a possible basis for future discussion, that the Denver and Willow Creek Formations may represent earlier Eocene deposits than are elsewhere known at the present time in the western region.

Eocene deposits with which the Denver beds may be compared are at present unknown. The small interior basin about Florissant, Colorado, situated only sixty miles a little west of south from Denver, has been quite thoroughly described by Professor S. H. Scudder,* and its flora and fauna by Lesquereux, Cope and Scudder. From the very abundant plants, insects and fishes of the Florissant beds it has been supposed that they are equivalent with certain parts of the Green River Eocene, but this reference is not thought fully justified, by Cope.† In his "Cretaceous and Tertiary Floras" Professor Lesquereux describes 152 species of fossil plants from the Florissant beds, and but *one* of these is included in the Golden Flora as described by the same author. Such a difference seems quite remarkable in view of the fact that the Laramie flora has so much in common with various Tertiary horizons.

It is usually assumed by those who have written concerning the Tertiary deposits of the West, that in the Eocene period the plains area east of the Rocky Mountains was almost entirely a continental region, and that no seas or lakes existed there to receive sediments equivalent to those of the Great Basin. This assumption rests, however, on a very imperfect and general knowledge of the district in question. The known destruction of a large part of the Denver beds prior to the Monument Creek epoch suggests that other deposits may have existed which were either entirely destroyed or are now represented by as yet unidentified remnants, corresponding to the Denver and Willow Creek beds.

As an example of our lack of knowledge concerning even the best known regions of the west, may be cited the discovery by Mr. R. C. Hills of 8000 feet of Tertiary strata at the eastern base of the Sangre de Cristo range in the Huerfano river basin of southern Colorado.‡ These strata rest uncomfortably on Laramie and Colorado Cretaceous. They are provisionally

* Bulletin, U. S. G. and G. S., vol. vi, No. 2, p. 279, 1881.

† U. S. G. S. of Ter., vol. iii, Book 1, pp. 3, 10, 1884.

‡ Described in a paper entitled "The recently discovered Tertiary Beds of the Huerfano River Basin, Colorado," read before the Colorado Scientific Society, December 3, 1888. To be published in the Society's "Proceedings" for 1888.

assigned by Mr. Hills to the Eocene though no fossil remains have yet been determined. Above these beds are still others, assigned provisionally to the Pliocene.

The present article is intended to present some facts established in a special work. But the facts have a more or less direct value in considering many of the important problems of Rocky Mountain geology. Some of these questions have been hinted at in discussing the age of the Denver Formation, but a further development of the bearings of the facts stated is a task requiring a wide experience in various fields, and this presentation I gladly leave to my chief, Mr. S. F. Emmons, who will give a broader treatment of the subject in the monograph upon the Denver Basin. My sincere thanks are due to Mr. Emmons for his kindness and courtesy in approving the publication of this article.

Note.—Mr. Eldridge has recently ascertained that the name "Willow Creek" has already been applied to several local Formations in this country, and he has therefore decided to call the Formation between the Laramie and the Denver the *Arapahoe* instead of the *Willow Creek.* This decision was reached too late to allow of correction in the body of the above article. Arapahoe is the name of the county in which the city of Denver is situated, and the beds in question are there very prominently developed.—W. C.

Art. XXX.—*Events in North American Cretaceous History illustrated in the Arkansas-Texas Division of the Southwestern Region of the United States;** by Robt. T. Hill.

During the last two years the writer has been permitted by the joint effort of Dr. John C. Branner, State Geologist of Arkansas, and the Director of the United States Geological Survey to investigate the stratigraphic and paleontologic conditions of the northern and eastern termination of the Texas Cretaceous, and to trace out its detailed relations to those of the Gulf and western states with their accompanying phenomena. The condition of knowledge previous to that time was fully set forth in this Journal for October, 1887. From later investigations I am able to present the following brief

* The southwestern region of the United States may be defined in stratigraphic terms as those portions of Arkansas, Texas, Indian Territory, southern Kansas, New Mexico and Arizona, south of the Uinta and Ozark uplifts and between the Sierras on the west and the great Atlantic timber belt on the east. Its principal divisions are the Arizona-Utah or Grand Cañon; the Rocky Mountain or New Mexican; the West Texan or Permo-Triassic; the Central Texas Paleozoic: and the eastern or Arkansas-Texas Cretaceous division lying between the last and the western borders of the Tertiary strata of the Mississippi embayment, as laid down upon Hitchcock's Geological Map of the United States.

sketch of the principal historical events recorded in their formations, and also a preliminary section which approximately outlines the Cretaceous history of the United States east of the Sierras.

Continental limitations at the beginning of the Cretaceous.

Early in these investigations it became apparent that the marine sedimentation of both divisions of the Cretaceous section had been limited on the north by an older continental shore line which must be defined before the subsequent history could be traced. The present remnant of this ancient shore line in the whole Neozoic history of the region was found to be a more or less connected orographic system, with a score of local names, which extends from the Ouachita river in the vicinity of Malvern and Hot Springs, Arkansas, almost due west through Indian Territory into the Panhandle of Texas. The remnant of this mountain system consists of some of the highest and most sharply defined ridges above the surrounding plain in America, as in western Arkansas, south of the Arkansas river, or again of strings of small knobs, as in the Potato hills of Indian Territory; but whatever their name or shape, it is every where evident that they are the now greatly degraded remnants of a series of nearly vertical folds which once constituted a continuous mountain system which was elevated at the close of the Paleozoic.

The former extent of this system can not be stated, for its present eastern termination was truncated abruptly and obscured by late Cretaceous and Tertiary deposits of the Mississippi embayment, while its western continuation is buried beneath Permian, Cretaceous and Quaternary sediments of the Texas Panhandle and obliterated by the later uplifts of the Rocky Mountain regions. The exact stratigraphic relations of this system to the Paleozoic area of Central Texas have not been determined, except that the latter's eastern margin presents a succession of sediments similar to those of the former, and its western border records an early Mesozoic history not seen along its eastern.* It is also evident that it was completely covered by sediments during the two great subsidences in Cretaceous time, while the eastern half at least of the Arkansas Indian Territory system remained above sea-level until present time.

* The western border of this Central Paleozoic region, which presents an entirely different system of strata from the eastern, will be treated in another paper.

The first Epoch of Subsidence.

Along the southern border of these mountains from the Little Missouri in Arkansas westward to the 98th meridian, thence southward to the Brazos along the eastern border of the Central Texas Paleozoic region, can be seen, resting with a slight dip upon the highly disturbed Carboniferous rocks and beneath the more calcareous chalky sediments of the Fredricksburg Division of the Comanche series, a littoral formation which marks the beginning of Cretaceous history in the region and whose beds, as far as the writer knows, are the oldest undoubted Cretaceous in the United States, except what are perhaps its eastward continuation, the Tuscaloosa and Potomac formations of Alabama and Maryland. This formation, as seen in its typical exposures along the Murfreesboro-Ultima Thule road in Arkansas, is composed of several hundred feet of variegated sands and clays, resembling in color the Potomac formations as seen in the railroad cuts at Baltimore, and, in addition, then fissile layers of shell-bearing limestone and great beds of gypsum and lignites, associated with a vertebrate and molluscan brackish-water fauna, which, notwithstanding our prejudices against trans-oceanic correlations, is unmistakably identical in general lithologic and stratigraphic features with the Purbeck and Wealden of England and Germany. This fauna, in addition to a profuse and unstudied flora, consists of Dinosauridæ and brackish water Mollusca including millions of individuals of a few species such as Corbiculidæ, Viviparus, *Ostrea Franklini* of Coquand and the undoubted *Pleurocera strombiformis* Schloth., so characteristic of the Wealden of Europe and not before found in America. These fossils with a single Ammonite are all indicative of its Wealden or transitional Jura-Cretacic age. West of the Paleozoic area of Central Texas, the writer has found only the sediments of this formation, but not its fossils. Its eastern termination is covered by the Upper Cretaceous and Quaternary. South of the Brazos, as at Austin, its position is occupied by a great deep marine chalk formation, now metamorphosed into hardest marble, which has strong Jurassic affinities. The Trinity formation, as it has been named, can be directly seen underlying the more calcareous and deeper marine beds of the Comanche series at many places, and clearly marks the interior shore line of the oldest American Cretaceous, as well as the beginning of a great subsidence which initiated that epoch and gradually covered the whole of the Texas Paleozoic area. How far the waters of the Atlantic extended southward and westward is yet unknown. Its northern limit was the unnamed mountain system above mentioned; for none of the lower (Fredricksburg) sediments of this division of the Cretaceous have until recently been found north of it. [Since this paper has been prepared for press, Prof. Crogin has noted the occurrence of rocks which belong, in my opinion, to the undoubted Comanche Series and probably the Trinity.] This subsidence, which has been overlooked in previous geological history, was profound and long continued. The evidence of its depth is recorded in the rocks and fossils of the Comanche series, which throughout consist of a deep infra-littoral deposit of chalk with and without flints, impure chalk and chalk marls often hardened into limestone, uniformly extending over wide areas and gradually succeeding the littoral Trinity beds. The thickness of these sediments increases southward, sometimes reaching 2000 feet. At Austin they are over 1500 feet. The evidence of a greater subsidence southward and absence of sediments northward indicate a continental condition in the latter region during Jurassic time and the possible continuation of deep sea conditions during that period in southern Texas and northern Mexico—a possibility which, as will be shown in another article, may be a fact, as indicated by an undescribed system of rocks in those regions.

The long continuation of this subsidence is well shown by its fauna. First, by the remarkable uniformity in the distribution of its successive horizons. The fauna of the Washita limestone horizon, in the section at the close of this paper, is almost identical at El Paso and at the Arkansas-Choctaw line, some 900 miles apart. The horizon of the remarkable and unique Exogyra arietina clays extends from Indian Territory to Presidio del Norte nearly 500 miles, with no perceptible variations in the outcrops. The long continuation of this subsidence is also shown by the gradual change which the species, a large number of which are identical with European Cretaceous forms, underwent without sedimental break. The species of Echinodermata, Ostreidæ, Gasteropoda, etc., of the Fredricksburg division are replaced in the Upper or Washita limestone by other forms of the same or allied genera, so similar in some predominant feature and at the same time so specifically different as to clearly show a line of progressive evolution in this epoch.* The time of this subsidence, as shown by paleontological evidence was Neocomian and Middle Cretaceous. It is also shown from its absence that this subsidence was not so extensive along the margins of the Appalachian regions. In fact, there is some circumstantial evidence that its northern shore limit, a portion of which is preserved to us in the Arkansas-Indian Territory orographic remnant, must have continued eastward without deflecting northward,

* The writer has in press a complete revision of the species of this division which will contain further mention of this fact.

as shown by the phenomenal outcrops in the salines of Louisiana and on the island of Jamaica.*

The Comanche epoch of subsidence was closed by the great elevation of an extensive land area of which little is as yet known, except that it must have endured a length of time sufficient for the complete modification of species, for not one of those of the Comanche series has thus far been found to pass upward into the later beds of America, although one or two are found in Europe. The records of this elevation are two-fold. First, an unmistakable and omnipresent unconformity between its beds and those of the succeeding Upper Cretaceous—the Meek and Hayden section of the northwest and its Atlantic coast equivalents. Second, the littoral conditions indicated by the land flora of the Dakota sandstone which must have been deposited along its shore line, marking the next great epoch to be described. This unconformity is seen not only in the absolute lack of parallelism in beds and the complete lithologic and faunal changes, but also in the fact that the same basal horizons of the Upper Cretaceous rest at different places, owing to unequal erosion, upon different horizons of the eroded surface of the lower Comanche series. The elevation at the close of the Comanche epoch is also illustrated by the disturbances recorded in the strata of southwestern Texas as shown in the following trans-section of the Austin-New Braunfels unconformity at Austin, the Upper Cretaceous series resting unconformably upon the greatly disturbed strata of the lower. The Comanche series are here greatly faulted along the fold of what could be appropriately termed the most eastward of the series of American monoclines and which marks the first plateau, the eastern margin of which continues westward to the Rio Grande. This elevation evidently took place before the beginning of the Upper Cretaceous.

* The peculiar occurrence of Cretaceous limestone in certain salines of Louisiana, some two hundred miles coastward from the main area of the Cretaceous exposures, was noted by Dr. Eugene W. Hilgard in various publications, but before the presence of any marine beds, except the Upper of the Cretaceous system, had been admitted in this country. Some two years ago, Judge Lawrence C. Johnson of the U. S. Geological Survey showed the writer some specimens of the material recently collected from these "Cretaceous Islands." They were found to be both lithologically and paleontologically identical with the marine Cretaceous of the Comanche series of the west Central Texas. The nearest outcrop of the main area of the formation is at Cerro Gordo, Arkansas, on the Choctaw line, and all the area intervening is covered by Quaternary deposits. Why these islands should occur along this Cretaceous "backbone" of Louisiana as Hilgard has termed it, can only be explained upon the hypothesis that there exists in that vicinity some ancient and as yet undescribed disturbance. Another datum which adds interest to this inquiry is the fact that upon the island of Jamaica, as personal observers and the reports of the Geological Survey of Great Britain have led me to believe, there are also Cretaceous rocks of the same horizon, directly in the strike of the Louisiana outcrops. In view of these facts, the investigation of Cuba is awaited with much interest, for it is probable that these outcrops were once continuous.

The second Epoch of Subsidence.

Following this mid-Cretaceous land epoch there was another profound subsidence. This epoch may be said to include geographically, stratigraphically, and paleontologically what was lately known as all of American Cretaceous history and which with slight modifications in correlation, is the section of Meek and Hayden and includes all the Upper Cretaceous of the Northwest, New Jersey and Alabama, except the basal, Tuscaloosa and Potomac beds, in the two latter regions. The paleontologic and sedimental sequence is continuous. In all these regions the grand development of the Lower Cretaceous strata of the Comanche series is missing, and the upper division rests either unconformably upon the basal littorals, equivalents of the Trinity beds, as in New Jersey and Alabama, or upon the pre-Cretaceous rocks of the mid-Cretaceous continent, as in the northwest. In Texas, however, this Upper Cretaceous system, which attains an even greater development

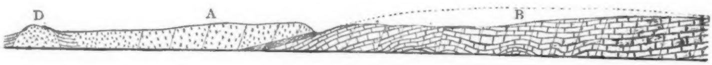


Fig. 1. Section across the Austin-New Braunfels unconformity, Travis county, Texas, showing disturbances at close of Upper (A) and lower Cretaceous (B), and unconformity between these systems. Basaltic extrusion (Pilot Knob) at D.

than in the typical "Nebraska" region, rests every where unconformably upon the Comanche series. The unbroken succession of the formations of this Upper Cretaceous, recorded both in Texas and the northwest by its sediments, is as follows:—(1) sands, (2) clays, shales changing upward into calcareous shales, (3) chalk, (4) chalk marls, (5) sandy marls, (6) sands with littoral fossils indicating a period of slow prolonged subsidence and gradual emergence.

This was the most profound submergence in all Mesozoic time, the Atlantic ocean having extended continuously, as shown by the remarkable identity of sediments similarly situated in relation to the shore line and by its fossils, from British America southward around the Appalachian continent. Its history is similar to that of the lower division—a long continued and gradual submergence, the sedimentation of which is marked by an immense chalk* deposit followed by a gradual transition upward without break into arenaceous littorals.

* The question of chalk in the North American Cretaceous is fully discussed in my report on the Geology of Southwestern Arkansas. It is sufficient to say that in sections of this basal Upper Cretaceous chalk, kindly prepared by Mr. J. S. Diller of the U. S. Geological Survey, were found almost a repetition of the foraminifera of the European Upper Cretaceous chalks.

Disturbances and Differentiation at the close of the American Cretaceous.

The uniformity of the littoral fauna at the close of the Upper Cretaceous is shown by a comparison of the species of the Ripley, Navarro and Pierre-Fox Hills beds. This similarity is in remarkable contrast with the great differentiation which followed it; for at the close of the Cretaceous, that emergence so well known to American geologists took place, which lifted the western interior region permanently above oceanic invasions. That the southern trans-Mississippi Gulf-Cretaceous was also slightly lifted above sea level is shown by a slight but unmistakable unconformity found in Arkansas, at Elmo, Texas, and elsewhere between the beds of these periods. The oldest littoral beds of the marine Tertiary (Lignitic), which are mostly composed of sediments derived from the soft strata of the underlying Cretaceous, are distinguishable from them only by a slight non-conformity sometimes accompanied by a thin sub-stratum of siliceous pebbles. This unconformity is made more certain, however, by the recent discovery of unmistakable paleontologic evidence. As in the case of the mid-Cretaceous non-conformity, the basal Tertiary rests upon different horizons of the Upper Cretaceous, owing to inequalities in its erosions. In Texas, southwest of Bastrop and Austin to the Sabinas river in Mexico, for a distance of 300 miles, there is a more conspicuous and unmistakable sign of the disturbances at the close of the Cretaceous than this unconformity, and this is an elevation accompanied by a line of many basaltic outbursts* in close proximity to, but not immediately connecting with the line of elevation along the Austin-New Braunfels unconformity above mentioned, which seems to have been a line of weakness since Jurassic times. The basaltic outcrops occur at no less than fifty places in a line from near Yegua Hills in Bastrop County southwest via Hays, Kendall, Bandera, Kerr, Nueces and Val Verde counties to the Santa Rosa mountains in Mexico. Pilot Knob, seven miles southwest of Austin, is a typical example. This is a small dome-shaped protuberance of columnar basalt rising through the Upper Cretaceous chalks which surround it on all sides and producing in them a quaquaversal dip of ten degrees, and metamorphosing them into saccharoidal marble at the contacts. In decomposing, the basalt becomes amygdaloidal and zeolitic. The whole exposure has the appearance of a truncated laccolite. Throughout the whole region, as seen in fig. 1, there are other evidences of the presence of these igneous rocks beneath, as seen in the dome-like disturbances and meta-

* Conjointly with Mr. E. T. Dumble, the writer will publish at an early day, a paper upon this remarkable igneous area.

morphism. It is evident that the extrusions took place at or after the close of the Cretaceous, and probably belong in the same category with similar phenomena reported at Rockwall in north Texas, in the Chickasaw Nation, and in Arkansas.

Post-Cretaceous events which have concealed Cretaceous history.

The inequalities between the two great formations of the Cretaceous have been greatly obliterated by subsequent history, as illustrated in the following section along the Arkansas-Choctaw line, across Little and Red rivers, wherein can be seen the leveling and concealment produced by an early Quaternary subsidence, which has also worn away much of the mountains.

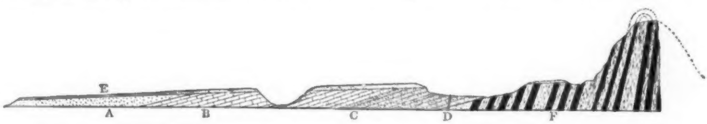


Fig. 2. Section forty miles in length north and south, along the Arkansas-Choctaw line showing the sequence of the Cretaceous formations, their relation to the Paleozoic Mountain axis F, and their post-Tertiary degradation by the Quaternary subsidence E. Upper Cretaceous, A; Comanche series, B; Trinity formation, C; Intrusive dike, D.

The whole Cretaceous history, as seen in the region of its most typical sediments, can be summed up as two profound subsidences, separated by a land epoch. These have left in their sediments two great chalk formations, as shown in the following table. The history of these subsidences has hitherto been confused owing to the fact that the littorals of one of them in regions favorable for study have been mistaken for the whole. Although each of the faunas and sediments of the two formations represents an unbroken series, I have mentioned for each horizon distinguishing species of Ammonites, Ostrea and Echinoderms.

University of Texas, March 7, 1889.

Events.		EPOCHS.		Distinguishing Fossils.	Prevailing Sediments.	Thickness W. Texas.
V. V. Tertiary Land EPOCH.						
IV. Second profound Marine Subsidence.	UPPER CRETACEOUS. Continuous sediments.	*Northwest U. S.*	*Texas.*		Sedimentation unbroken.	
		1 { Fox Hills-Pierre.	Navarro beds. Exogyra ponderosa Marls.	Am. placentaceras. O. vesicularis. O. costata. Cassidulus aequoreus.	Calcareous sands. Marly clays.	[1] 1000
		2 Niobrara.	Austin-Dallas Chalk.	Inocerami. Nautilus.* Radiolites Austinensis. Hemicidaris Texanus Roem.	Chalk marls. Chalk gradating upward into next.	[2] 600
		3 Benton.	Eagleford Shales. (fish beds).	Scaphites, fish teeth. Inocerami.	Clay shales becoming more calcareous upward.	[3] 300
		4 Dakota.	Lower Cross-Timber beds.	Leaf imprints. Few casts.	Sands, Lignites, etc.	[4] 200
III. Mid-Cretaceous Land EPOCH.						2100
II. First Profound Marine Subsidence.	LOWER AND MIDDLE CRETACEOUS. Continuous sediments.	*Washita Division.*				
		Denison beds		O. crenulimargo Roem	Alternations of clay, lime and sand	100
		Vola, or red chalk Limestone		Vola quinquecostata Sow. and undescribed fauna	Massive lime bed with oxidizing iron	50
		Exogyra Arietina clays		Exogyra arietina Roem	Calcareous, green clay shales	100
		Washita limestone		G. Pitcheri, var. Navia; Terebratula Wacoensis; Macraster elegans Sh.; O. carinata Lamk. and O. sinuata	Impure chalk	100
		Fredericksburg Division.				
		Hippurites limestone			Metamorphosed chalk	750
		Caprotina "		Caprotina (Requienia)	" "	
		Comanche Peak limestone		Am. pedernalis V. B.; Toxaster Texanus Roem; O. flabellata (E. Texana) Gold	" with flints	300
		Trinity Beds.		Am. Walcotti, sp. nov. A. Franklini Coq.; Pleurocera strombiformis Schlot; Dinosaurs		300
I. Jurassic Land north of Texas. Deep seas to west and south.						1800 2100 3900

ART. XXXI.—*A General Method for determining the Secondary Chromatic Aberration for a double Telescope Objective, with a description of a Telescope sensibly free from this defect;* by CHARLES S. HASTINGS.

A FORMER paper by the writer* described a method of finding the practicable combinations of three kinds of glass to produce an objective without secondary chromatic aberration. The result of the investigation showed that there had been several optical glasses studied and described, notably one by Fraunhofer and one by Van der Willigen, which would meet the practical requirements of the problem in combination with types of optical glass now readily procurable. Since publishing that paper the writer has made very many experiments with a large variety of glasses, not only those made specifically for optical purposes but many others, without, however, finding any really useful combinations until recently. But within a few years the variety of material at the command of the working optician has been enormously increased by the invaluable labors of Dr. Schott and Professor Abbe; and within the last two years the results of their investigations have been put at the command of the working optician by the manufacturing firm of Schott and Company of Jena. What Professor Abbe and Dr. Zeiss have accomplished with these newly acquired means in the improvement of the microscope is a most interesting history familiar to all, but their utility in the way of improving the telescope has not been thoroughly investigated. With a view to this investigation the writer procured a number of these glasses of the most notable optical peculiarities just after the catalogue of Schott and Co. came into his possession, omitting, however, those which were known not to be permanent under ordinary atmospheric exposure; for, although small lenses of microscope objectives may be used with such care that the deterioration of the surfaces need not be serious for many months or even years, the larger and far more expensive lenses of the telescope must be permanent or their final cost would render them wholly impracticable. This purely practical limitation was imposed notwithstanding that the manufacturers recommended a number of combinations which would yield greatly diminished secondary dispersion if it were dispensed with.

The method employed in the paper cited above is rigidly accurate, but very laborious in its application. It required the making of a very accurate prism of each variety of glass and

* This Journal, III, vol. xviii, p. 429.

the determination of eight or ten indices of refraction for known wave-lengths as well as a protracted calculation. The manufacturers supply in their catalogue, however, the approximate refractive indices of their materials for several known wave-lengths, and the differential refractions with considerable accuracy. As the character of the color correction of an objective depends upon the latter quantity, it seemed that some method might be devised for a systematic study of all the materials founded upon these given constants, and thus avoid the large amount of labor required in the old method. This consideration led to the following solution.

The power of a binary lens having the sum of the reciprocals of the radii of the two lenses respectively A and B is

$$\varphi=(n-1)A+(n'-1)B,$$

which, for a definite value of n, we will arbitrarily assume to be unity, thus:

$$\varphi_0=(n_0-1)A+(n'_0-1)B=1. \qquad (1)$$

For an achromatic combination we must have

$$\frac{d\varphi}{dn}=0=A+\frac{dn'}{dn}B \therefore B=-A\frac{dn}{dn'} \qquad (2).$$

The value of the differential coefficient in this equation is a variable, but the value which should be taken for the best color correction for visual purposes has been shown to be* that corresponding to a wave length of about 5164. By employing *these* values of n and n' in the above equations and designating them by n_0 and n'_0, equation (1) becomes the condition of definite power and (2) that of achromatism.

We now wish to find the expression for the secondary chromatic aberration. We may write

$$\varphi_0=(n_0-1)A-(n'_0-1)\frac{dn_0}{dn'_0}A;$$

$$\varphi_n=(n_0+\delta n-1)A-(n'_0+\delta n'-1)\frac{dn_0}{dn'_0}A; \text{ whence}$$

$$\varphi_0-\varphi_n=\delta\varphi=(\delta n-\frac{dn_0}{dn'_0}\delta n')A.$$

But in the paper of vol. xviii, cited above, it was shown that the refractive index of one species of glass can be expressed as a simple trinomial function of that of another with practically absolute accuracy, whence

$$n'=\alpha+\beta n+\gamma n^2$$

$$\delta n'=(\beta+2\gamma n)\delta n+\gamma\delta n^2; \text{ also}$$

$$\beta+2\gamma n=\frac{dn'}{dn}=\frac{dn'_0}{dn_0} \text{ nearly, and } \gamma=\tfrac{1}{2}\frac{d^2n'}{dn^2}.$$

Substituting the value of $\delta n'$ in the expression for $\delta\varphi$, we have

* This Journal, vol. xxiii, p. 167.

$$\delta\varphi = -\tfrac{1}{2}A\frac{dn_0}{dn'_0}\,\frac{d^2n'}{dn^2}\,\delta n^2, \qquad (3)$$

which is the measure for the secondary chromatic abberration for a binary lens of materials n and n' and power φ. Although it is, as appears from the method in which it was derived, an approximation, it is found to be perfectly accurate to three significant figures from the wave-lengths A to H inclusive.

If we already have the constants of the equation expressing the relation between n' and n the calculation of $\delta\varphi$ is easy and the method obvious. For the Crown 1219 and Flint 1237 of my paper on double objectives cited above, which may be taken as typical specimens of the crown and flint glasses used in the construction of astronomical telescopes during the last half century, the value of $\delta\varphi$ is $-27{\cdot}1$; but if we have not sufficient data to enable us to calculate the values of α, β and γ, or if we wish to avoid the labor of determining them, we may content ourselves with three indices for each kind of glass employed and be confident of a useful approximation to the true solution if the corresponding wave-lengths are well distributed through the spectrum. Thus if the indices for the Fraunhofer lines C, D and F, are given, we may substitute in the above equations, n_D for n_0, $\frac{n_F - n_C}{n'_F - n'_C}$ for $\frac{dn_0}{dn'_0}$, and for $\frac{d^2n}{dn^2} = 2\gamma$ the value deduced from the equations:

$$n'_F - n'_D = (n_F - n_D)\beta + (n_F - n_D)^2\gamma$$
$$n'_D - n'_C = (n_D - n_C)\beta + (n_D - n_C)^2\gamma.$$

Such a ready approximation gives $\delta\varphi = -30{\cdot}0$ for the glasses above mentioned.

In the catalogue of the Jena manufacturers are given the approximate indices of refraction for the line D, and to a much greater degree of precision, the differences of the indices for various intervals in the spectrum including the intervals C to F and D to F. Since the color characteristics of a combination depend upon the differences far more decidedly than upon the absolute value of the indices, as has already been stated, we have in this list all the data necessary to secure an approximate solution to the problem by the method described. We may most conveniently proceed by selecting some one from the list and then find the value of $\delta\varphi$ for each combination of the others with it for a definite change of wave-length of light; or, what is far better for our end in view, calculate the value of the coefficient of δn^2 in the expression for $\delta\varphi$. If we call this coefficient k its value will be $-\tfrac{1}{2}A\,\frac{dn^0}{dn'_0}\,\frac{d^2n'}{dn^2}$. Such tabulated values of k would give us a notion whether a combination was subject to a large secondary chromatic aberration or to a small one, but the numbers would not be proportional to the aberrations because of the variable factors δn^2; but if we multiply the number k by $\left(\frac{dn}{dn_1}\right)^2$, where n is the index for the glass which is to be combined with that common to the whole series of pairs, and n_1 is the index for another glass arbitrarily assumed to have the standard dispersion, we shall have a series of numbers all of which are to be multiplied by the same quantity, namely, δn_1^2, to find the secondary chromatic aberration for a binary objective of each pair. These numbers we will designate by k'. In order to make the comparison with an objective of the ordinary type, I have chosen No. 37 of Schott and Co.'s catalogue, an ordinary flint of the kind generally employed in telescope objectives, for the negative lens of all the combinations, and No. 13, which is an ordinary crown glass, as the material of standard dispersive power. The following table contains the results of the computations thus indicated. The first column contains the catalogue number of the glass combined with No. 37; the second column contains A, the sum of the curvatures of the two surfaces of the positive lens, and the third, under B, the sum of the curvatures of the two surfaces of the flint lens; finally, the fourth column contains k', which may be regarded as the true measure of the secondary chromatic aberration. In short, if r_1 and r_2 are the radii of the positive lens, r'_1 and r'_2 those of the flint No. 37 lens, we have for a binary lens of focal length unity,

$$A=\frac{1}{r_1}+\frac{1}{r_2},\quad B=\frac{1}{r'_1}+\frac{1}{r'_2},\quad k'=k\left(\frac{dn}{dn_{13}}\right)^2.$$

Inspection of the table shows—First: that only one of the binary combinations having "ordinary dense flint" as one component is practically free from secondary chromatic aberration, namely, No. 30. This is described in the catalogue as a silicate flint with relatively high refractive power. Although the combination demands rather deep curves for the lenses, it is in my opinion by far the best which the present resources of practical optics affords, and is sensibly perfect. The inconvenience of excessive curvature could be reduced by making the objective of three lenses, the flint 37 being a double concave between two positive lenses of flint 30, or, perhaps better, in the case of large telescopes, increasing the ratio of focal length to aperture. This conclusion stands or falls with the accuracy of the data supplied by the catalogue, for, although there are strong reasons for supposing the data good, I have not seen either of the materials in question.

Second: that there are only two combinations for which k' is positive, those of 66, an "ordinary light flint," and rock salt. The first of these is of no practical interest on account of the large numerical values for A and B, but the case of rock salt is worthy of a moment's discussion. The numbers show that it is possible to make a telescope objective of rock salt and ordinary telescope flint which, with moderate curvatures, shall give a *negative* secondary chromatic aberration, that is, which would show the center of a stellar-image purple inside of the focal plane instead of outside as in the familiar case. This peculiarity of rock salt I discovered a long time since. It is of interest since it enables us to eliminate all secondary chromatic aberration by combining a relatively strong binary lens of rock salt and flint with a weak binary of crown and flint, or, in short, to make an absolutely achromatic combination of the three materials named. I had calculated such an objective and commenced making a pair for spectroscopic work, when the publication of the Jena catalogue suggested combinations of more practical value.

Table of constants of binary objectives composed of various substances combined with flint, No. 37.

No.	A	B	$-k'$	No.	A	B	$-k'$
1	3·97	−1·68	25·5	24†	5·91	− 3·83	36·4
2*	3·85	−1·84	20·0	25	6·62	− 4·23	34·4
3	3·86	−1·96	19·8	26	7·06	− 4·46	21·1
4†	3·84	−2·04	22·3	27	7·58	− 5·29	33·2
5	4·46	−2·04	25·3	28†	8·64	− 6·81	34·5
6	4·68	−2·21	25·4	29	10·48	− 7·98	21·5
7	4·71	−2·30	27·1	30	10·6	− 8·61	0·5
8	4·77	−2·35	23·6	53	5·02	− 2·94	23·3
9	4·80	−2·40	23·0	54	5·65	− 3·06	24·1
10†	4·91	−2·37	35·8	55	5·45	− 3·35	17·2
11	4·99	−2·41	25·7	56	6·31	− 3·71	18·2
12	4·67	−2·43	26·2	57	5·84	− 3·72	20·5
13	4·92	−2·48	28·7	58	6·09	− 3·90	19·9
14	5·00	−2·58	17·0	59	6·03	− 3·92	18·9
15	4·93	−2·59	25·6	60	6·42	− 4·24	15·4
16	4·63	−2·64	21·6	61	7·03	− 4·65	14·2
17	5·21	−2·70	24·4	62	7·53	− 5·42	18·8
18	5·29	−2·76	22·5	63	10·7	− 8·10	11·0
19	5·21	−2·77	26·9	64	13·0	−10·4	12·3
20	4·70	−2·95	22·2	65	12·9	−10·2	5·8
21†	5·17	−2·96	35·5	66	25·8	−23.4	−13·3
22†	5·42	−3·19	32·2	Rock Salt	11·67	− 8·52	− 6·5
23	6·21	−3·74	18·5				

* That in my possession not permanent. † Not permanent.

Third: that it is easy to select from the table triple combinations such that the secondary dispersions shall be completely eliminated. The process would be the following:—Take a *negative* binary lens of some materials of which the value of $-k'$ is large and of such a power, φ', that $\varphi'k'$ equals $-k'$ for a binary having a small value of this constant. These two binaries combined will form a system of power $\varphi-\varphi'$ without chromatic aberration. Other things being equal those materials having the smallest numbers under A and B would be preferable. To illustrate: suppose we take combinations 3 and 37 and 10 and 37, the first having a small, and the second a large, secondary aberration. Take a negative binary of the second pair of power −0·553, which will give

$$A_{10}=-2{\cdot}72 \quad B_{10}=1{\cdot}31 \quad k'_{10}\varphi_{10}=19{\cdot}8 \quad \varphi_{10}=-0{\cdot}553\,;$$

add to this a binary of the first pair of which

$$A_3=3{\cdot}84 \quad B_3=-2{\cdot}04 \quad k'_3\varphi_3=-19{\cdot}8 \quad \varphi_3=1{\cdot}$$

and we have a triple lens for which

$$A_3=3{\cdot}84 \quad A_{10}=-2{\cdot}72 \quad A_{37}=-0{\cdot}73 \quad k'\varphi=0 \quad \varphi=0{\cdot}447.$$

The meaning of A_{37} is obvious when we remember that B_3 and B_{10} both express curvature sums for the same material, flint 37. To find the curvature sums for a focal length of one, we should have only to divide throughout by 0·447, which yields 8·59 −6·09 and −1·63. These are moderate curvatures, but in view of the fact that 10 is not a permanent glass I should prefer 3, 25 and 37, or 3, 27 and 37, although there are a considerable number of such triple combinations which may be useful and which may be gathered from a study of the table.

Fourth: that by means of the table we may also find the value of the secondary chromatic aberration for a binary composed of any two materials entered in it. For example, suppose we desire the color characteristic of a binary composed of Nos. 1 and 22, which is one of the combinations recommended by the makers as yielding an objective of notably diminished secondary aberration. Take a negative binary of 22 and 37 with a power of −0·527; its constants are:

$$A_{22}=-2{\cdot}85 \quad B_{22}=1{\cdot}84 \quad k'\varphi'=17{\cdot}0.$$

Combining this with the binary of 1 and 37 of power one, we have a binary lens of the two glasses in question (since the 37 eliminates) the constants of which are:

$$A_1=3{\cdot}97 \quad A_{22}=-2{\cdot}85 \quad k'\varphi=-8{\cdot}5 \quad \varphi=0{\cdot}473\,;$$

or, reduced to focal length of unity,

$$A_1=8{\cdot}39 \quad A_{22}=-6{\cdot}02 \quad k'=-18{\cdot}0,$$

whence we conclude that by this construction we only reduce the secondary dispersion one-third at a cost of permanence in one of the lenses.

Other combinations recommended for the end in view are 2 and 24, and 3 and 28. The first of these is optically by far the best, reducing the dispersion about five-sixths, but both the materials are perishable; the second pair is practically the same as 1 and 22, but 28 is not permanent. If we are content with a combination containing a glass which is not permanent we can find much better pairs than those suggested in the catalogue. For example, 2 and 22 reduce the secondary aberration

80 per cent with moderate curves; 3 and 24 by 90 per cent with still smaller curvatures; 3 and 22 form a combination without chromatic aberration, but requiring rather deep curvatures; 55 and 28 are also practically perfect, reducing the secondary aberration 98 per cent, but demanding somewhat deeper curves than the last pair.

If, however, we impose the condition that only permanent glasses shall be employed, which is an obviously imperative condition for a telescope which is to be used out of doors, the range of choice is very greatly reduced. The only pair suggested in the catalogue which is useful from this point of view is of Nos. 8 and 25. These give an improvement of 65 per cent over the ordinary objectives, but require the values $A_8=10{\cdot}7$ $A_{25}=-8{\cdot}29$; this combination would without doubt be very useful if we had nothing better. The above table, however, suggests at least two combinations which are better, one, that of 30 and 37, which, like 8 and 25, requires undesirably deep curves, but which gives an improvement of 98 per cent, and the other Nos. 14 and 27 which yields an improvement of 94 per cent and demands the somewhat more manageable curvature sums of 9·78 and −7·24.

The trustworthiness of the data of the catalogue is the only further element which we need to consider, since all the above conclusions rest upon them. There are three excellent reasons for placing the highest confidence in them. In the first place, emanating from so eminent a physicist as Professor Abbe they can hardly, by any possibility, be subject to systematic errors, which alone we have to fear. Secondly: If we arrange the materials according to their optical properties as given in the table above we find that they fall into groups suggested already by their chemical composition. Thirdly: In the various glasses which I have accurately determined the data of the catalogue are exactly what they pretend to be, that is, the errors of the indices of refraction are confined to the fourth place of decimals, and the differences of the indices to the fifth place.

Among the glasses in my possession are the Nos. 14 and 27, which, according to what appears above, form a most advantageous combination. Of these I made prisms, determined the optical constants with great precision, and then calculated an achromatic objective. There were two questions of interest which could only be answered by trying the objective. They were, first, whether secondary chromatic aberration reduced to about one-twentieth of its ordinary value could be detected by the eye; and second, how much the defining power of such an objective would surpass that of the familiar type. Thus, although after studying the prisms and computing the objective no doubt as to the validity of the conclusions from the table remained, it was highly desirable to try a telescope so constructed before publishing this paper. The largest objective which could be made of the pieces in my possession was of $2\frac{3}{4}$ inches clear aperture. This, though smaller than desired, was sufficient to give a fairly satisfactory answer to the questions. Accordingly the glasses were worked accurately to the curvatures and thicknesses corresponding to the computations and mounted for use. The astonishing beauty of the images in the new telescope was its most surprising feature at first. The familiar purple was wholly wanting, or at least, could only be recognized with the closest attention, with magnifying powers greater than forty to the inch aperture, and on objects most suitable to its exhibition. But the moment that the instrument was applied to astronomical use it was also evident that its defining power was remarkable. The companions to Polaris and Rigel, instead of being objects which require somewhat careful looking, as is the case with my eye and an ordinary achromatic of the same aperture, were strikingly plain. More difficult, but certainly seen, was the fifth star in ϑ Orionis. The binary star η Orionis was so well elongated that its position angle was estimated to within 5° of its true value; on the other hand ξ Ursai Maj. which I suppose to have at present a separation of $1''\cdot7$, was divided only with difficulty on a fairly good evening though it was supposed that it would be easy. Saturn showed all that I have seen with an admirable telescope of considerably greater apertures, including more than half of Ball's division, the ring C, a single belt and five satellites though Tethys and Dione have not been seen unless they had an elongation equal or greater than that of the end of the ring. Rhea has been seen in conjunction. By reference to the records of many observations which I have made with various telescopes the power of the new telescope was estimated as equivalent to a $3\frac{1}{2}$ inch objective of the ordinary construction. The powers used varied from 53 to 265 diameters with 194 as the most satisfactory for Saturn and for double stars.

Another method of determining the relative power of the telescope was by comparing the distances at which a table of logarithms could be read with it and a very perfect telescope of $2\frac{5}{8}$ inches aperture made a number of years ago, and with which I have observed a great deal. Allowing for the 5 per cent increase in size in the new instrument, the mean of five tolerably accordant determinations indicated a gain of 23 per cent, or that the new objective was equivalent to a $3\frac{3}{8}$ inch objective of the ordinary construction. This ratio of improvement is doubtless higher than would generally be admitted as possible by most opticians, but it must stand for the present as the best value attainable.

Yale University, March, 1889.

ART. XXXII.—*The distribution of Phosphorus in the Ludington Mine, Iron Mountain, Michigan;* by DAVID H. BROWNE. With Plates VIII–XIII.

[Paper read before the American Institute of Mining Engineers at its New York Meeting, February, 1889.]

ONE of the most difficult problems in the chemistry of iron ore, and one, so far as I am aware, the solution of which has never been attempted, has been the distribution, throughout the vein, of Bessemer ore, and its relation to the formation of the deposit. In those hematite mines in which both Bessemer and non-Bessemer ores occur, the sorting of the ore, as it lies in the deposit, becomes a problem of much economic as well as scientific interest. It would seem from a superficial examination, or indeed from any examination not conducted for this especial purpose, as if high and low phosphorus ores were mixed in inextricable confusion; and a mining chemist is very apt to fall into a system of adventitious analyses, taking first-class ore wherever he can find it, and overlooking its relation to the formation and position of the vein. I hope that a few notes, which I shall present on this subject, may be found worthy of consideration, as throwing a new light on this obscure topic.

During the last three years, while acting as chemist of the Lumberman's Mining Co., I have made some 3000 analyses of ore from the Ludington Mine, at Iron Mountain, Mich. These analyses were necessary in order to separate Bessemer and non-Bessemer ore which occurred intermixed in the deposit. During the last year I attempted in several ways to find some reason or method in the distribution of phosphorus; and have finally become cognizant of the arrangement herein outlined. I have been obliged to confine my attention to one mine, and of that, to that portion wherein the commercial quality of the ore was such as to demand systematic sampling and analysis. The analyses, therefore, and the conclusions drawn therefrom, are given merely as facts found to exist, and I do not claim that such sequence as I have noticed will obtain in all or every case. I simply state what results I have obtained in an investigation carefully conducted, and I give some conclusions toward which the data seem to lead.

The Ludington mine, like most on the Menominee Range, consists of several lenticular deposits of soft blue hematite. These deposits are contained between clay slates, which conform with the Huronian strata represented in the district. The main deposit is about 700 feet in length and perhaps 60 feet in width. It strikes N. 75° W., pitches 45° west, and dips from 70° to 80° N. The ore is a very rich, soft, friable, bluishblack hematite, occurring in thin laminæ, which cleave very readily from each other in the direction of the strike. These layers alternate in places with thin seams of calcium-magnesium carbonate. The ore analyzes from 65 to 68 per cent in iron, in silica from 1 to 4 per cent, and in phosphorus from ·005 to ·200. The ore is separated into Bessemer and non-Bessemer; about one-half falling below ·035 phosphorus; the rest averaging about ·075. At first sight, the ore upon analysis, seemed to have no regularity whatever in percentage of phosphorus. A room as stopped up, would change from Bessemer ore to non-Bessemer, or *vice versa* in a way at first totally inexplicable.

The fact that phosphorus exists as calcium phosphate led me to infer that some proportion between the percentage of lime and phosphorus might be found to exist; but such inference was not verified in practice. An ore containing 2 per cent of lime may contain almost no phosphorus, or may run high above Bessemer limit. Nor was any proportion manifest between the percentages of iron or silica and phosphorus. I have noticed jasper vary as much in percentage of phosphorus as any iron ore, and similarly a lean ore is just as likely to be Bessemer as non-Bessemer. The only difference I could find between Bessemer and non-Bessemer was this: As a rule a soft blue hematite high in phosphorus, has a brighter and more specular appearance than non-Bessemer ore of the same value in iron. This distinction, slight as it is, will not always hold good, and the separation of such ores must be guided solely by chemical analysis.

The fact that a bright ore was high in phosphorus, and that such ore was generally found near the hanging wall led me to search for some regularity of phosphorus distribution, dependent upon the position of the ore. After making analysis of the ore from any room, drift or winze, I marked the percentage of phosphorus in a map of that portion of the mine. Having thus obtained a chemical map of each room, I noticed in each a certain regularity which seemed to me to throw considerable light both upon this problem of phosphorus distribution, and upon the vexed question of the method of formation of the hematite ore deposits.

In order to give a clear idea of this relation I must first state a few facts with regard to the physical features of the deposit. As previously stated, the so-called "veins" of the Ludington mine stand nearly vertical, dipping north and pitching west. A horizontal cross section of the ore-body shows it to form an elongated lens about 65 feet in thickness at the center, tapering to an acute point at both ends (fig. 1). A vertical cross section shows the dip to the north, and also the fact that the hanging wall is more curved than the foot. A cross section of the Chapin Mine, which possesses the same physical features, shows this very plainly (fig. 2). A horizontal cross section of several small veins shows that the hanging wall curves toward the foot. On large veins the strata have been subjected to so much flexion that this curvature is not clearly seen, but on small veins it is unmistakeable (see fig. 1, *a*). I must here state that in the greater number of veins on the Menominee Range the dip is to the south, and hence what is called the hanging wall in the Chapin and Ludington Mines answers in them to foot wall. If we attempt to make an ideal vertical longitudinal section of the ore deposits it seems to have the shape given in figure 3. A study of the eastern and western limits of the Chapin Mine seems to verify this idea. Figure 18 shows a vertical longitudinal section of a small vein in which this shape is very noticeable. The ore will now be understood to lie in the form of lenticular deposits dipping north, and pitching west.

With regard to the content of phosphorus: the first thing noticeable was that if a room, in stoping up, changed from non-Bessemer to Bessemer ore, such change was liable to occur at the footwall side of the room. In making maps of those rooms in which change occurred it was also noticeable that the ore at the eastern end of the rooms was higher in phosphorus than that at the western end. The most typical room was No. 7 Room, 2 Shaft, 5th Level, which is outlined in figure 4. This room was, if I remember aright, about 3½ sets from east to west and four sets from footwall to hanging. A set, I may say, is a space 8 by 8 by 8 feet, outlined by the timbers used to support the back. From the ground plan of this room it will be noticed that the ore showed a marked regularity of formation. Follow the course of the hanging wall, and trace the increase of phosphorus from ·068 at the west hanging wall set to ·078, ·086, ·100 and finally ·156 on the east hanging wall set. Such increase is also noticeable in the ore in entry from ·060 to ·096 and, though less plainly on the footwall from ·020 to ·032. Beside this regularity there is a corresponding increase from footwall to hanging. Notice the gradual change from ·032 and ·028 on the foot, to ·045 and ·040 in the middle and ·156 and ·068 on the hanging wall. On inspection, figures 4 to 16 will also show the same peculiarity and a large number of average analyses corroborate the conclusion that in this mine, as a rule, the ore increases in percentage of phosphorus from footwall to hanging wall, and generally speaking from west to east. It frequently happens, however, that a streak of high or low phosphorus ore crosses a room from west to east, as in figures 4, 14, and 15. This seems to be due to the fact that one or more individual layers of ore were originally very high or very low in phosphorus, and such individuality has not been observed by subsequent changes. Moreover irregularity is very frequently noticed in the direction from west to east. Sometimes a decrease is manifest, and sometimes an increase, these being both easily accountable for. The analyses taken from west to east are not nearly so regular and uniform as those taken from foot to hanging wall; nor is this to be wondered at; for since the layers of ore present smooth surfaces in the direction of the walls, analysis taken along a series of sets on the footwall will represent roughly analyses of at most a very few layers of ore. In driving a drift, or stoping a room, or sinking a winze, on the other hand, where analyses are made, averages are taken of a large number of separate deposits, and as these deposits are much flexed and broken, the analyses show little correspondence. In the breast of a drift 8 feet wide, supposing each layer of ore has a thickness of half an inch, there will present themselves for analysis the edges of no less than 192 layers; and in consequence more confusion is liable, and does occur, in analyses taken east and west than in those taken north and south.

Having obtained thus a general idea of how the lines of phosphorus tend in two directions; the next question naturally is, what would be the lines of equal phosphorus content in any individual layer of ore. These, for want of a better term I have herein been obliged to term "isochemic lines." It is evident that analyses of ore in the breast of a drift, or in the bottom of a winze, would not give any clue to the isochemic lines in a particular stratum of ore, but would show the average of several hundred separate strata. It is also evident that no analysis would accurately represent the composition of a particular layer, unless this layer, in no case over half an inch, and rarely over one-quarter inch in thickness, could be followed by chemical analysis along drifts, and up slopes, and down winzes and shafts, for a distance in some way proportionate to the extent covered by the deposit of which it forms an infinitesimal thickness. This would be, and for me was, practically impossible. For analyses to be of commercial value, must show, not the amount of constituents in any particular stratum of ore, but the average of that amount of ore which a gang of men, working under contract, can take out of a given room, before other analyses be made. For this reason I have been obliged to confine myself to analyses which represent averages of a large number of layers; and from these analyses I have endeavored to outline the probable distribution of phosphorus in the separate strata. It is plain that if any single layer of ore shall have its percentage of phosphorus in some way modified by its method of deposit, every other layer subjected to the same conditions will be in similar manner modified, and consequently, analyses representing average of a large number of strata will show the characteristics common to each individual stratum.

In sinking a winze in No. 1 Room, 5 Shaft, 5½ Level, the following facts were noticed. The drift running east from the winze showed ore running from ·015 phosphorus to ·030; the winze as sunk passed through ore running from ·015 to ·029. Lines drawn from the point in the drift where a certain percentage of phosphorus was noticed to a corresponding point in the winze showed an angle of about 45° with the horizon. Also in sinking a winze in No. 2 R., 5 Sh., 5½ Level, similar lines of equal chemical composition were noticed. (See fig. 20.) In sinking 5 shaft from the 7th to the 8th Level, and in sinking the winzes in No. 1 and No. 2 Rooms it was noticed that the winzes passed through ore previously met with in drifts and winzes to the east. These isochemic lines will be easily seen in figure 21. If now we take a small vein as that composing No. 4 and No. 5 Rooms, A shaft, 6 Level, and attempt to outline the isochemic lines in the plane of the winzes the regularity is at once patent. On the entry the first-class ore was confined to the last set west in the room. As the room stoped up, this first-class ore was thrown more to the center of the room. The course of the isochemic lines is very plainly indicated by the average analyses marked in the map of this room. (Fig. 18.) The first-class ore continues steadily along the western boundary of the room, and the high phosphorus ore as steadily follows the course of rock to the east. A winze sunk in the room showed all the changes from low to high phosphorus, previously met with east of the winze in the entry. Analyses taken from a small and very characteristic lens of ore forming No. 4 Room, 1 Shaft, 6 Level, shows very clearly the tendency of isochemic lines to run in the same direction as the pitch of the ore, and also the tendency of phosphorus to increase toward the upper part of the deposit. (Figs. 10 and 11.)

In attempting to draw up a vertical longitudinal section of the western end of the deposit, the principal difficulty lay in reducing so many analyses to the same plane. In consequence of the impracticability of attempting to represent every analysis taken, and its relation to others in the same vein, I have been obliged to select those analyses which represent averages; and in the vertical longitudinal sections of various rooms the figures entered in the map represent average percentage in phosphorus of the ore in that particular place covered by the figures, and in the plane through which section is made. Fig. 19 gives the detail of various averages in 1 and 2 Rooms, 5 Shaft. While the ore left in the pillars has not been subjected to analysis, I have for the sake of clearness drawn through the pillars the isochemic lines indicated by the percentages in phosphorus in the rooms which they support. Figure 23 is an attempt to outline the curvature of isochemic lines in the course of 5 shaft from the surface to the 8th level. I have in my possession detail maps of the chemistry of the entire course of No. 5 shaft, showing the percentage of phosphorus in every eight feet cube of ore removed. As it would be impossible to reduce this map to the size of the engravings required for an octavo page and preserve at the same time the clearness of the figures therein, I have been obliged in drawing Maps 18, 19, 20 and 21, to omit more than two-thirds of the figures in the original drawings. Figure 23 will be understood then, simply as an outline sketch. By actual measurement the distances along various levels, through which certain average percentages of phosphorus obtained, have been carefully ascertained, and the exact points where change from Bessemer ore to non-Bessemer occurred located upon the section map to correspond. The curvature of the isochemic lines, therefore, is in accurate correspondence with the course of high and low phosphorus throughout the western end of the Ludington mine. The drawing of various rooms and pillars is in this map omitted. The curving lines, when close together, represent high phosphorus ore; the arrows indicate direction of Bessemer ore; and the figures represent averages of several hundred analyses for phosphorus taken in the immediate neighborhood indicated thereby.

From this figure (23) it will be noticed that on the upper levels the greater portion of the ore is non-Bessemer. At the west end of the mine, a small streak of Bessemer ore follows the shaft, gaining toward the west until the 4½ and 5th levels are reached, where the Bessemer ore flexes toward the east and merges into the broad current of first-class ore which flows upward and eastward from the lower levels of 5 shaft. The non-Bessemer ore follows the western boundary of rock, and seems to accumulate also in shoals outlined by projections or intrusions of jasper, which break the flow of the current.

On stoping up No. 1 Room, 7th Level, through ore gradually increasing in phosphorus, a seam of rock was encountered. As analysis of the drift over head had shown low phosphorus, and the shaft 50 feet to the left had passed through Bessemer ore, I concluded that the ore above this rock would be of first-class quality. This prediction was made entirely on the supposed consistency and continuity of isochemic lines, as no ore had been taken from above this rock for analysis. I was at this point called to New York on business, and before leaving, left word with the mining captain that any ore found above this rock should be sent up for first-class ore. On returning to the mine three weeks later I found that this rock had been pierced and some 200 tons of ore from over head sent up and dumped upon the Bessemer stock pile. Analysis of this ore showed it to be from ·011 to ·027 phos. which will be seen to agree with other analyses along this isochemic line. (Fig. 21.)

Below this 7th Level the intrusion of rock seems to have caused an inflow of non-Bessemer ore. It appears as if the rock had formed in shoal water on its lower side, and into this shallow the calcium phosphate had drifted. I have noticed in a large number of instances this tendency of rock occurring as vein matter to alter the percentage of phosphorus in the adjoining ore. In fact I do not know of any case wherein a horse of jasper did not in some way alter the proportion of phosphorus in the ore penetrated thereby. The statement that high phosphorus follows rock is one which will be corroborated by any one familiar with the mine under consideration.

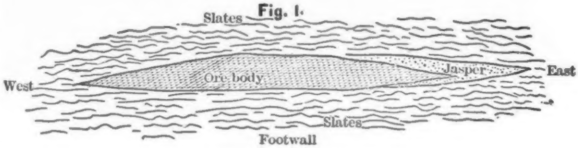
Another fact I must state is this: On the upper levels of No. 5 shaft almost all the ore was exceedingly high in phosphorus. The ore found on the lower levels shows a greater uniformity, the difference between Bessemer and non-Bessemer ore being less evident than on the upper levels. It was no uncommon occurrence on the third and fourth levels to find streaks of ore as high as ·350 phosphorus. Now such ore is very rarely met with. The average of non-Bessemer ore in the west end of the open pit and the upper levels of No. 5 shaft was somewhere near ·150 phosphorus. The averages of non-Bessemer at present obtained is probably ·075 or ·080. Again, on the upper levels the greater part of the ore near No. 5 shaft was non-Bessemer; at present the converse is the case, the first-class ore occupying the greater portion of the deposit. To state in general terms, the tendency of the phosphorus on this vein seems to be to increase with the distance from the lower point of the deposit. This is not true of the eastern end of the deposit, at No. 1 shaft, in which the upper levels are largely Bessemer ore. This seems due to the fact that a horse of rock splitting up the deposit has thrown the current of Bessemer ore to the east. This Bessemer ore, occurring on the upper levels of No. 1, is of the same content in phosphorus as that on the 5th and 6th levels of No. 5 Shaft, and the high phosphorus ore on the lower levels of No. 1 is the same as that now being met with on the 7th and 8th levels of No. 5 shaft. Fig. 23.

In endeavoring to correlate these isochemic lines with the physical phenomena of the deposit, the only theory which will, to my mind, furnish adequate explanation, is that of aqueous deposition. The easy longitudinal cleavage of the laminæ of ore, the curvature in small veins of the hanging wall toward the footwall, and the hydrated muddy look of the ore next the footwall, all seem to indicate that the ore was deposited in hollows of the exposed slates which now form the hanging wall. Furthermore since it is well understood that the almost uniform tendency of all deposits east of the Mississippi River is in a line from southwest to northeast, it is very probable that this deposit, as originally laid down, was no exception to the general rule. If we suppose that the ore was formed in hollows in the hanging wall, and was covered by the footwall slates, and that this bed has been tilted up from the north side, through an angle of 100° to 110°, it will be readily understood that the original trend of the deposit becomes the complement of the present pitch of the ore. This supposition explains also the strike of N. 75° W., and the fact that what is now the hanging wall seems to have been the original bed of deposit. It is improbable that the tilting has been from the south side upwards through an angle of 70° to 80°; for if this had been the case the ore would pitch east at the same angle at which it now pitches west.

In the American Journal of Science for January, 1889, Professor Van Hise suggests that the soft ores of the Gogebic range have been formed by the action of percolating waters containing carbonic acid, which, acting upon previously deposited carbonate of iron, has dissolved iron therefrom; and this dissolved iron has been precipitated by oxygen-bearing, or alkaline waters from the surface. This theory, while seeming to explain the formation in the Gogebic mines studied, seems less probable as applied to the mines on the Menominee Range. Here the ore rests directly upon clay slates containing none of the unaltered carbonates found in the Gogebic Range. The ore also lies not in trough-like formations, but in regular basins of lenticular shape. The ore exhibits none of the nodular form spoken of in Professor Van Hise's paper, and the stratification is remarkably even and regular.

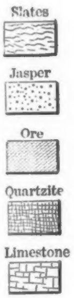
The suggestion made by Mr. R. D. Irving in the American Journal of Science for Oct., 1886, that the ore has been washed into its present position from previously precipitated beds of carbonate, seems to me very plausible, and is borne out in a large measure by the chemistry of the ore body. I should, however, suggest this change, that the original deposits of iron and lime were not as crystallized siderite and calcite, but as hydrous oxide and carbonate of iron with intermixed calcareous deposits. This finds analogy in the formation of beds of bog iron ore in the present day. It is worthy of note that such beds of altered bog ore do exist in the Huronian strata represented in the upper Peninsula of Michigan. Any one familiar with the non-Bessemer ores of the western end of the Menominee Range must have been struck with the remarkable

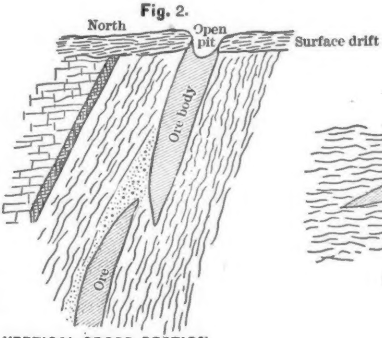
Fig. 1.



HORIZONTAL SECTION

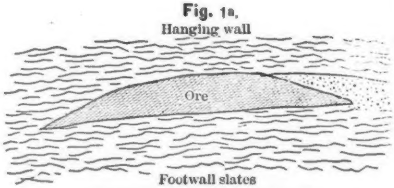
Fig. 2.





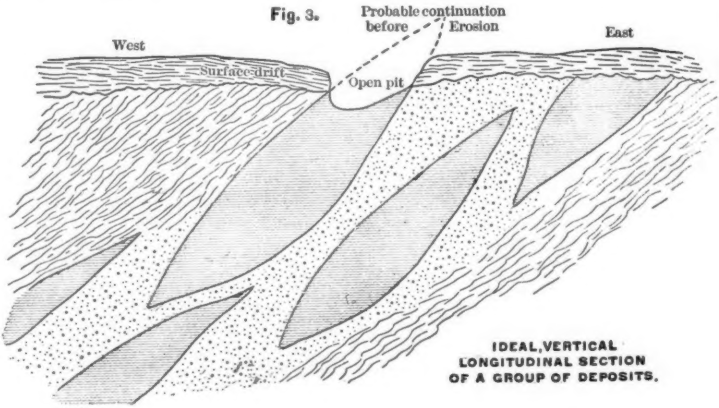
VERTICAL CROSS SECTION

Fig. 1a.



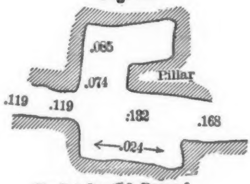
HORIZONTAL CROSS SECTION

Fig. 3.



IDEAL, VERTICAL LONGITUDINAL SECTION OF A GROUP OF DEPOSITS.

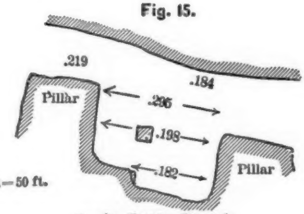
Fig. 14.



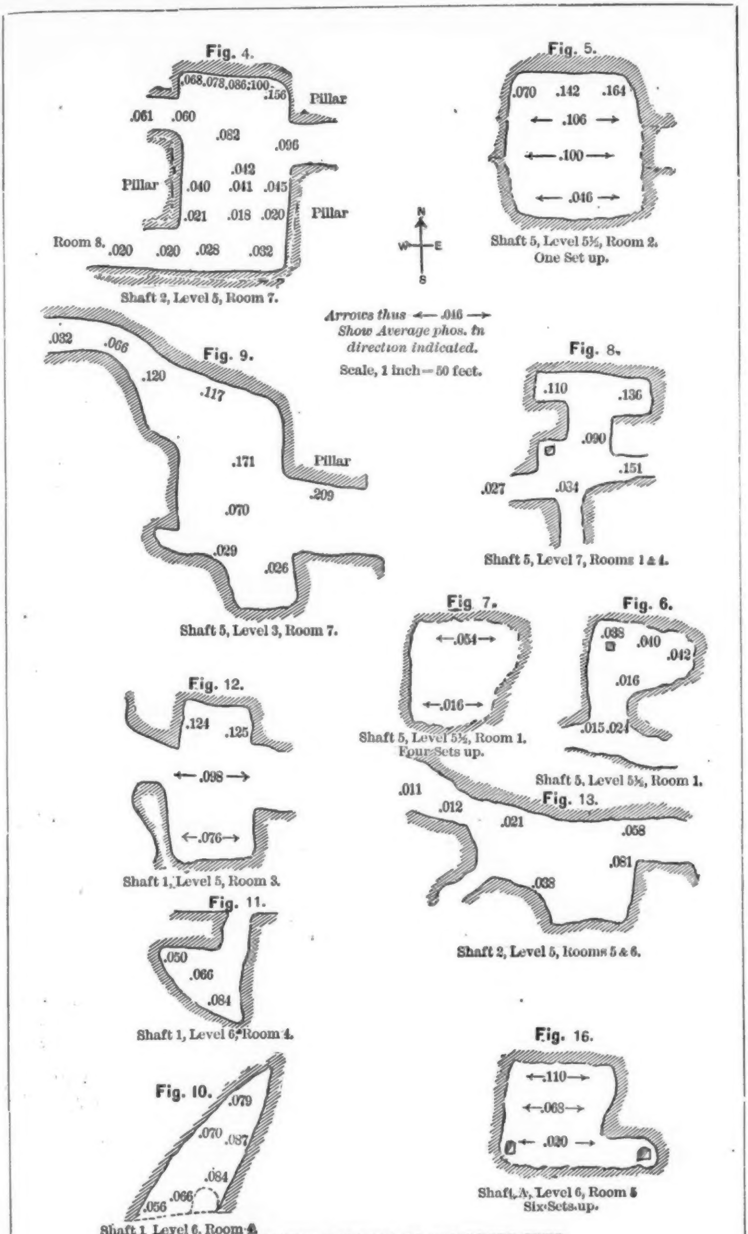
Shaft 2, Level 3, Room 6.

Scale, 1 inch = 50 ft.

Fig. 15.



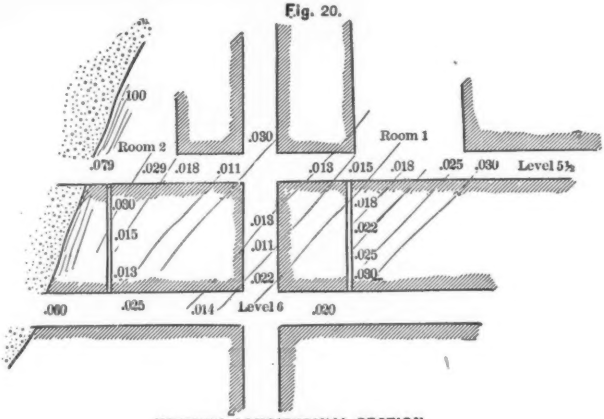
Shaft 5, Level 4, Room 1.



HORIZONTAL SECTIONS OF LUDINGTON MINE.

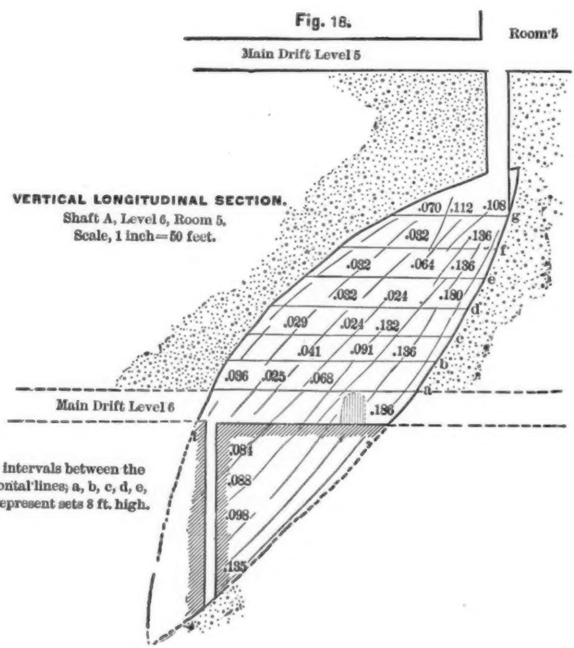
EXCEPT FIG. 10. WHICH IS A VERTICAL SECTION.

Fig. 20.



VERTICAL LONGITUDINAL SECTION
Levels 5½ & 6, Rooms 1 & 2.
Scale, 1 inch = 50 feet.

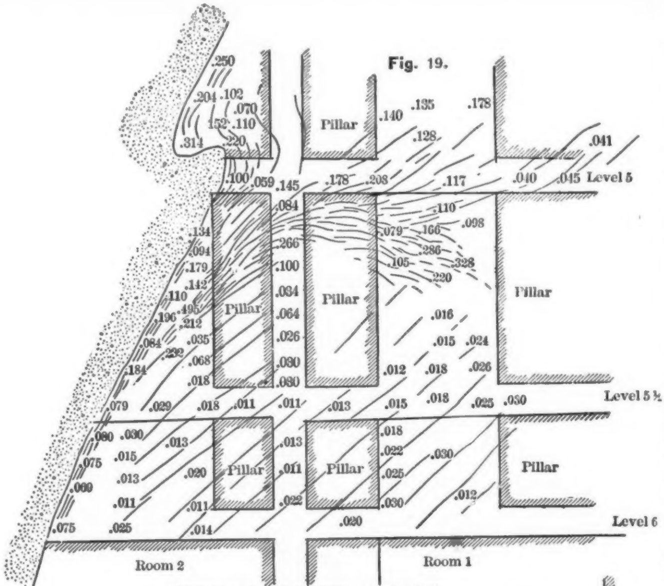
Fig. 18.



VERTICAL LONGITUDINAL SECTION.
Shaft A, Level 6, Room 5.
Scale, 1 inch = 50 feet.

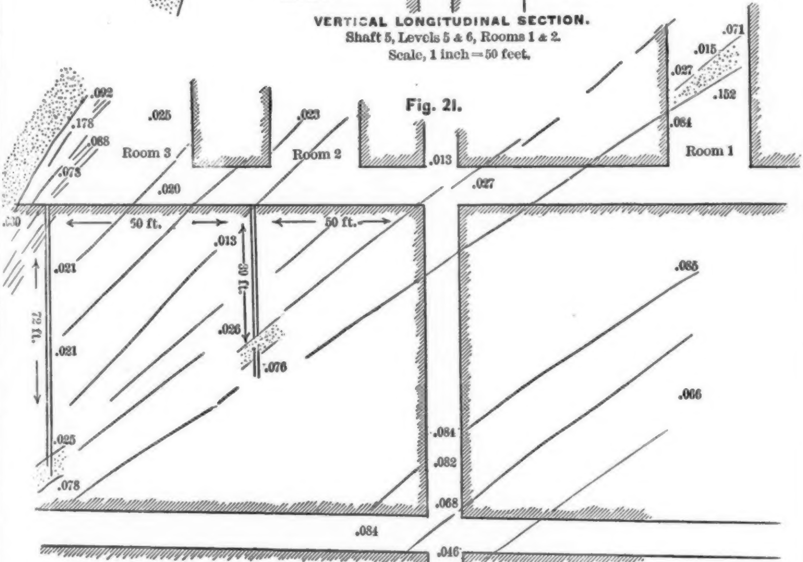
The intervals between the horizontal lines, a, b, c, d, e, f, g, represent sets 8 ft. high.

Fig. 19.



VERTICAL LONGITUDINAL SECTION.
Shaft 5, Levels 5 & 6, Rooms 1 & 2.
Scale, 1 inch = 50 feet.

Fig. 21.



VERTICAL LONGITUDINAL SECTION.
Level 7, Rooms 1, 2, & 3.
Showing depth of winzes.

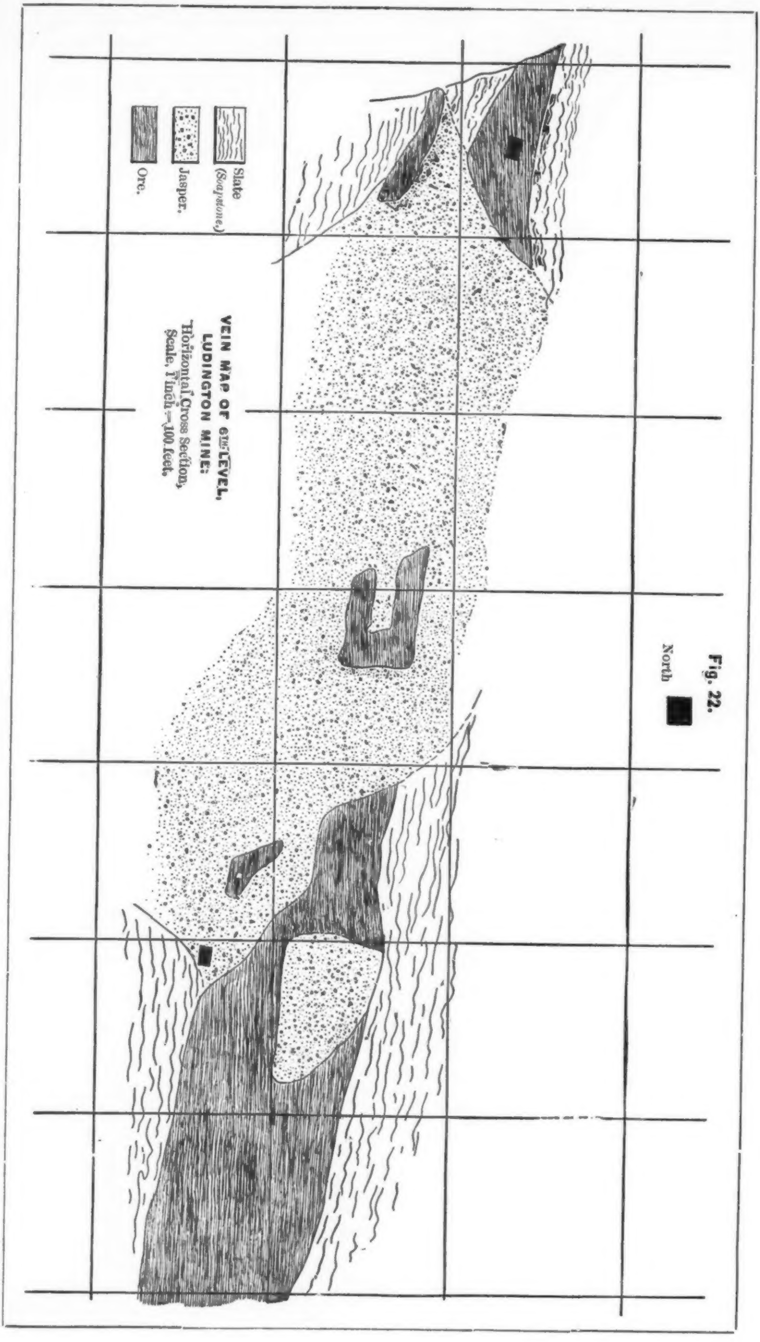
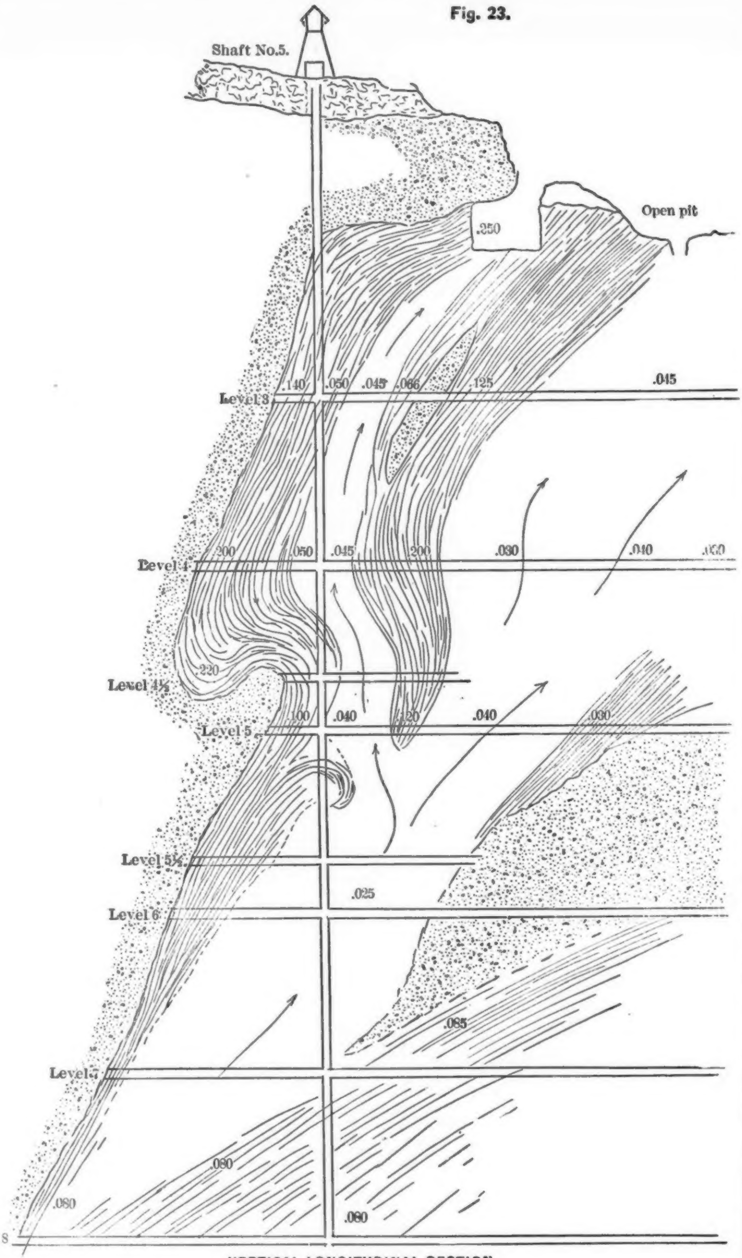

Slate (Soapstone.)
Jasper.
Ore.
VEIN MAP OF 6th LEVEL,
LUDINGTON MINE:
Horizontal Cross Section,
Scale, 1 inch = 100 feet.
North

Fig. 22.

Fig. 23.



VERTICAL LONGITUDINAL SECTION.
West End of Main Deposit.
Ludington Mine.
Scale, 1 inch = 100 feet.

difference between these ores and the soft blue hematites occurring east of the Menominee River. The ore taken from the Nanaimo, Paint River, Iron River, and other non-Bessemer mines has all the non-laminated, massive, porous, reddish-yellow appearance of an altered bog ore. With this also the frequent occurrence of graphite, the high phosphorus, the intermixed calcareous matter, and the low percentage of iron seem to agree. From such beds as these, I incline to think the iron of our soft blue hematite mines has been carried. It is interesting to notice how this supposition is strengthened by chemical proofs. I have often noticed that very dilute solutions of hot acids will dissolve from an ore almost all of its phosphorus, with only a slight percentage of iron. Indeed it is possible, in this way, to remove and estimate the phosphorus without bringing the ore into solution. Nor is acid always necessary, for in a large number of instances also verified by experiment I have found that ore exposed for several years to the weather will have appreciable amounts of phosphorus dissolved and removed. Now if water acidulated by carbonic acid acts on a bed of bog ore, it will carry therefrom a large amount of phosphorus in proportion to the amount of iron removed. If such thermal water flows into a shallow valley or lake, the acid will be lost by evaporation, and precipitation of phosphorus and iron will take place.

The theory of aqueous deposit of these ore bodies, as drawn from chemical evidence, is then briefly as follows. From previously deposited beds of bog iron ore, by the action of acidulated water, iron, lime, silica and phosphorus were dissolved. The first solution contained a large amount of phosphorus in proportion to the amount of iron dissolved. On coming into hollows in the surface of the exposed slates, the acid solution, losing acid by evaporation, deposited iron, as hydrated oxide, which carried down an amount of phosphorus proportionate to the amount of iron precipitated. As the acid became still weaker crystals of carbonate of lime and magnesia settled out, forming a layer of carbonates. A second inflow of water would tend to dissolve these carbonates and precipitate another layer of iron. In similar manner by successive inundations the depression became filled with alternating layers of iron ore and calcium-magnesium carbonates, each layer being as a rule lower in phosphorus than the preceding one. As the carbonates were more soluble than iron, the probability is that the greater portion was replaced by iron ore. Moreover as both calcium and iron phosphate are of lower specific gravity, and more soluble than the hydrated oxide of iron, the tendency of the water was to carry these phosphates toward the lower end of the lake, and to deposit them in shallow water, along banks of previously precipitated silica, and in places where evaporation was most rapid. By reference to fig. 23, it will be seen that those parts of the deposit where the current must have been deep and unbroken are low in percentage of phosphorus, while the high phosphorus as a rule occurs where the deposit is shallow or the ore pinched out by rock. After the deposition was complete, further action of the water would stir up the upper layers of ore, and mix them with suspended sand or clay, while the iron and phosphorus were carried farther along to be deposited in other depressions to the northeast. As jasper occurs as vein matter, and in laminæ cleaving in the same line as the ore, it would seem, either that the jasper had been produced by precipitation with the iron, or that subsequent action of water has eroded the beds of iron thus formed and substituted silica for the iron removed.

A study of the vein map of the 6th level at the Ludington mine, on which level almost the entire deposit was replaced by jasper, and in consequence the formation of the jasper was most evident, seems to show that the jasper is a later formation than the ore. It will be seen by reference to fig. 17 that the jasper deposit widens toward the footwall. A large horse of jasper occurring in the ore at the eastern end of the vein shows this very plainly. This would seem to indicate that at a time when the ore deposit was about half its present width an inflow of silica-bearing water eroded the ore deposit and deposited silica in place of the iron abstracted. The greater width of the jasper at the footwall also suggests an erosion of the original ore bed and a subsequent deposition of silica. Had the silica been the primary deposit the ore would be widest at the footwall instead of at the hanging.

The explanation, however, of the deposits of silica bedded in the same plane with the ore, in some cases stopping sharply against ore, in others merging gradually into it, is at present a very difficult problem. The explanation suggested by Prof. Van Hise seems to me more satisfactory than any other, with the provision, however, that subsequent erosion must be taken into consideration. Whatever explanation of the horses of jasper be adopted, it is evident that both ore and jasper after formation were covered by the slates and other superincumbent strata, and in some local upheaval tilted up from the north and brought into their present position.

The erosion of the Glacial period removing several hundred feet of the outcropping strata has cut away a large part of the original deposits, and from the ore thus eroded have been formed the surface deposits or washes of ore found at Keel Ridge, Quinnesse and Norway mines.

The subsequent action of water upon the upturned edges of the eroded deposit would of course in large measure modify the chemical peculiarities of the ore. This is proved by the fact that the greatest regularity of isochemic lines is manifest where the ore is shielded from surface water by the overhang of the western jasper; and by the fact that at the eastern end of the mine where the ore has been exposed under the drift, this regularity is not so manifest. That the original direction of deposition was from west to east is shown by the occurrence underground of strong streams of water flowing from the rock at the western extremity of the ore deposit.

The theory of aqueous deposit will explain, as will no other, the marked regularity of isochemic lines and their peculiar curves, the regular decrease of phosphorus from hanging wall to foot, the alternation of carbonate of lime and oxide of iron, the ripple-marked hanging wall, the uniform lamination of the ore and the hydrated muddy deposit next the footwall. It also suggests explanation of the general features of the Menominee Range, and the gradual change from high phosphorus and low iron ores resembling altered bog ores at its western extremity, through regular deposits of high iron and lower phosphorus, to the immense washes and surface deposits of exceedingly low phosphorus ore which mark its eastern termination.

The conclusions herein given are not intended as general and applicable to all cases. They are intended simply as an explanation of certain chemical phenomena noticed in a careful study of the Ludington mine. Whether such tendencies would be found in other mines I am not prepared to say; but the fact that irregularity of chemical composition has been often noticed does not preclude the possibility of a method or law of irregularity existing. I incline to think that careful and systematic chemical research applied to the soft ore deposits of the upper Peninsula would bring to light many interesting facts with regard to their manner of deposit, and would lead to a more thorough understanding of one of the most practical and interesting problems of economic geology.

EXPLANATION OF FIGURES. PLATES VIII TO XIII.

Fig. 1. Horizontal cross section of small vein.

Fig. 1*a*. Horizontal cross section of vein showing curvature.

Fig. 2. Vertical cross section of same, showing curvature of hanging wall.

Fig. 3. Vertical longitudinal section showing form of hollows in which ore is deposited. This section is ideal, but corresponds with several known sections.

Figs. 4–16. Horizontal cross sections of various rooms in the Ludington mine. In all figures the hanging wall is toward the top of the plate, and the west end toward the left, as shown in fig. 4. Figures indicate percentages of phosphorus in the ore removed.

Fig. 18. Vertical longitudinal section of No. 5 room, A shaft, 6 level, in the plane of the winzes, showing curvature of isochemic lines. The figures show percentage of phosphorus in the ore at the points indicated.

Fig. 19. Vertical longitudinal section of 5 shaft between the 5th and 6th levels. Dotted lines are lines of equal chemical composition.

Fig. 20. Vertical longitudinal section of 5 shaft between 5½ and 6 levels, showing ore in winzes and its relation to ore in drifts.

Fig. 21. Vertical longitudinal section of 5 shaft between the 7th and 8th levels, showing depth of winzes and distances along drifts, and method of establishing an isochemic line.

Fig. 22. Vein map of 6 level, Ludington mine.

Fig. 23. Sketch map of the isochemistry of 5 shaft from surface to the 8th level. The dark lines represent high phosphorus ore, the open spaces and arrows low phosphorus ore and its direction of increase. The space covered by these lines and the figures is the ore deposit in part worked out. The jasper at the left shows the western limit of the ore deposit. The jasper occurring to the right of this constitutes what is known as horses of rock splitting up the vein and breaking the regularity of the deposit.

These figures are drawn from maps made by Mr. Chas. N. Snow, engineer of the Ludington mine, Mr. Per Larson, engineer of the Chapin mine, and Mr. E. Everett of Ishpeming, to whom I am much indebted for their kind assistance in the preparation of this paper.

Art. XXXIII.—*Palæohatteria* Credner, *and the Proganosauria;* by Dr. G. Baur.

One of the most important discoveries in Paleontology has just been made by Professor H. Credner of Leipzig, well known by his publications on the Stegocephalia of the Permian of Saxony.*

This discovery consists of a series of nearly complete skeletons of a reptile from the lower Permian (Rothliegendes). This reptile, with the exception of *Stereosternum* Cope, from the Carboniferous (?) of Brazil, is the oldest yet known. Professor Credner calls it *Palæohatteria* from the close resemblance to *Hatteria* from New Zealand, the only living member of the Rhynchocephalia. But since *Hatteria* is preoccupied by *Sphenodon*,† this new form really ought to be called *Palæosphenodon.* It is placed by Professor Credner among the Sphenodontidæ, but it has to be considered as the type of a distinct family, which may be called the *Palæohatteriidæ*, or *Palæosphenodontidæ*, in case the name *Palæosphenodon* shall be admitted by Credner.

Characters of the Palæohatteriidæ. — Skull resembling *Sphenodon;* lacrymal free from præfrontal; bones showing centers of ossification, like those of Stegocephalia; interclavicle

* Credner, Hermann: Die Stegocephalen und Saurier aus dem Rothliegenden des Plauenschen Grundes bei Dresden, vii Theil. *Palæohatteria longicaudata* Cred. Zeitschrift Deutsch. Geol. Gesellsch., 1888.

† *Sphenodon* Gray, 1831; *Sphenodon* Lund, 1839 (Mamm.); *Hatteria* Gray, 1841; *Sphenodon* Agass. 1843 (Fish.) Baur, G., Erwiderung an Herrn Dr. A. Günther. Zool. Anz., No. 245, 1887.

rhomboidal with long distal process, nearly of the same form as that of *Belodon*, *Aetosaurus*, and *Proterosaurus;* ilium expanded at the upper end ; claws well developed.

One of the most important characters of *Palæohatteria* consists in the presence of five distinct tarsal bones in the second row, one for each metatarsal. In this it agrees with *Stereosternum* Cope, which I placed in a new order, *Proganosauria.**

The *Mesosauridæ*† are a specialized family of this order. The *Palæohatteriidæ* on the contrary are a generalized group ; *they are Proganosauria, which gave origin to the Rhynchocephalia.*

I give now a new definition of the *Proganosauria.*—Humerus with entepicondylar foramen ; five distinct tarsal bones in second row, one for each metatarsal ; condyles of limb-bones not ossified ; pubis and ischium broad plates ; each set of abdominal ossicles consisting of numerous pieces.

1. *Palæohatteriidæ.*

Characters given above.

2. *Mesosauridæ.*

Skull elongate, with numerous very sharp and slender teeth ; first metatarsal the shortest, fifth metatarsal the longest bone. No claws.

The *Proganosauria* are Reptiles with many characters of the Batrachians ; the *Palæohatteriidæ* is the most generalized group among the *Monocondylia* (Sauropsida).

Some points in Professor Credner's paper need correction :

1. There are two not three or more sacral vertebræ.

2. The bones called "hyoids" may just as well be the epipterygoids (columellæ). If they represent hyoids, they resemble these elements in *Belodon* and *Ichthyosaurus.*

3. There is no free lacrymal in *Sphenodon* as figured by Credner.

4. The quadratojugal of *Sphenodon* is overlooked.

5. The so-called basisphenoid is probably the parasphenoid.

6. The foramen in the humerus is *entepicondylar* not ectepicondylar.

7. The carpal bones of *Proterosaurus* are wrongly determined ; the bone called radial represents the first central bone.

8. The figure of the embryo of "*Monitor*" is erroneously explained, by both Hoffmann and Credner ; the bone called tars. 5 is the metatarsal 5.

* Baur, G. On the Phylogenetic Arrangement of the Sauropsida. Journ. of Morphol., vol. i, No. 1, Sept, 1887.

† I use the family-name *Mesosauridæ.* It is probable that *Mesosaurus* Gervais is the same as *Stereosternum* Cope.

Some important results can be reached from the study of this ancient form:

1. The antorbital foramen or fossa is a secondary formation; all forms of Reptiles having this fossa descended from forms without it.

2. The peculiar short bone in the hind foot of the Reptilia, which some consider as a metatarsal 5, others as a tarsal 5, certainly represents the *metatarsal* 5.

3. The bones called epiplastra and endoplastron in the Testudinata are doubtless the clavicles and interclavicle. The clavicles and interclavicle of the Amniota represent the "mittleren und seitlichen Thoracalplatten" of the Stegocephalia and other Batrachia. These elements must be considered as dermal ossifications; the connection with the shoulder-girdle is secondary.

4. *The origin of the so-called "Abdominal ribs."* The *abdominal ossicles* or "ribs" are found to-day only in *Sphenodon* and the Crocodilia; the "abdominal ribs" of *Chamæleo, Polychus*, etc., are entirely different elements. There are no abdominal ossicles like those in *Sphenodon* found in *Palæohatteria, Proterosaurus, Hyperodapedon.* In these we have bundles of scale-like pieces. These we have to consider as the homologue of the same elements in the Stegocephalia and as the abdominal ossicles in the Rhynchocephalia, Ichthyosauria, Plesiosauria, Pterosauria, Crocodilia, Dinosauria, Saururæ. In nearly all these forms each set of abdominal ossicles consists of one or two median pieces and one lateral one on each side; but in the Ichthyosauria we find very often one median piece and *two* lateral ones on each side.

The idea, at first pronounced by Owen, that the plastron of the Testudinata has developed from abdominal bones is very probable.

5. *The foramina in the humerus of the higher Vertebrata.*—
a. No foramen: Batrachia.

b. Foramen entepicondyloideum: Proganosauria, Theromora,† Mammalia.*

c. Foramen entepicondyloideum and foramen ectepicondyloideum: Sphenodontidæ, some humeri from the Permian of Russia.

d. Fossa entepicondyloidea and foramen ectepicondyloideum: Atoposaurus, Sapheosaurus, Nothosauridæ, part.

e. Foramen ectepicondyloideum: Testudinata, Lacertilia. Nothosauridæ part, Rhynchocephalia, part.

f. Fossa ectepicondyloidea: Belodon, Champsosaurus, Testudinata, part, etc.

g. No foramen: Crocodilia, Dinosauria, Pterosauria, Plesiosauria, Pythonomorpha, Birds, etc.

* If not lost by specialization.

† The name Theromorpha has been changed by Professor Cope to Theromora.

The oldest Reptiles, the *Proganosauria*, had only the foramen entepicondyloideum; from those the *Theromora* and *Mammalia* took their origin.* Some of the *Proganosauria*, which we do not know yet, probably developed also the foramen ectepicondyloideum; such forms connected the *Rhynchocephalia*. Then the entepicondylar foramen was lost again and later also the ectepicondylar foramen.

New Haven, Conn., March 5th, 1889.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *On the Presence of a New Metal in Nickel and Cobalt.*—Krüss and Schmidt have discovered a new metal in both nickel and cobalt. These chemists had undertaken to determine the atomic mass of nickel and of cobalt, using for the purpose the pure material prepared by Zimmermann, the method of Winkler and the atomic mass of gold as corrected by Krüss, 196·64. When the solution of sodium-gold chloride was treated with metallic nickel or cobalt, the precipitated gold was found to be mixed with a small quantity of one or the other of these metals thrown down apparently by a secondary action. By dissolving the weighed precipitate in aqua regia, precipitating the gold with sulphur dioxide, subtracting its mass from that of the precipitate, the excess of nickel or cobalt was ascertained and allowed for. But still the method did not give concordant results. Finally it was noticed that in washing the gold precipitate obtained by sulphur dioxide from a solution of a previous precipitate thrown down by cobalt, the red color of the filtrate, due to cobaltous chloride, became gradually paler and finally acquired a pale greenish color. This portion of the wash water was collected and evaporated in a platinum dish, and left after ignition a slight residue which dissolved in concentrated hydrogen chloride solution on warming, with a beautiful green color, the color disappearing on cooling. A similar result was obtained when nickel was used to precipitate the gold. A chloride solution was obtained on evaporating the wash-water and dissolving in hydrogen chloride in which no nickel or other known element could be detected. In order to obtain a larger quantity of the new substance, nickel sulphide was treated with ammonium sulphide so long as the solution became brown. The new element became concentrated in the residue. So an increase of the new chloride in the mother liquors was obtained by crystallizing the double chloride of mercury-nickel or mercury-cobalt from a

* Baur, G. Ueber die Kanaele im Humerus der Amnioten. Morph. Jahrbuch, vol. xii, 1886, pp. 299–305. On the Phylogenetic Arrangement of the Sauropsida. Journ. of Morphology, vol. i, No. 1, Sept., 1887.

solution containing equivalent quantities of both chlorides. Finally it was observed that the new oxide was soluble in fused caustic alkali, in which cobalt and nickel oxides are insoluble; and thus it was obtained pure, 50 grams nickel oxide yielding about one gram of the white oxide. Its properties are as follows: The acid chloride solution is not precipitable by hydrogen sulphide, but ammonium sulphide produces in neutral solutions a blackish sulphide. Ammonia throws down a voluminous white flocculent precipitate, not soluble in excess. Potassium hydrate acts similarly. On igniting the oxide moistened with cobalt solution, only a weak brown color results. Even after strong ignition, the oxide is soluble in the cold in a 27 per cent hydrogen chloride solution. With excess of acid, the chloride is green, but the neutral chloride is white and gives with water a colorless solution. The oxide does not change its weight when ignited in hydrogen. The metal can be obtained, however, by electrolyzing the chloride solution or by reducing the chloride in a current of hydrogen. It is black, brownish-black in thin layers, dissolves readily in acids when produced electrolytically, more difficultly when produced at a high temperature. Further researches on the new metal are in progress by the authors.—*Ber. Berl. Chem. Ges.*, xxii, 11., January, 1889. G. F. B.

2. *On the Atomic Mass of Tin.*—BONGARTZ and CLASSEN have undertaken a redetermination of the atomic mass of tin. For this purpose they employed four methods: 1st, the oxidation of the tin to stannic oxide; 2d, the electrolysis of ammonium stannic chloride, $SnCl_4(NH_4Cl)_2$; 3d, the electrolysis of potassium-stannic chloride; and 4th, the electrolysis of stannic bromide. The mean of eleven experiments by the first method gave the value 118·7606 for the atomic mass of tin; the difference between the maximum and the minimum values being 0·459. The mean of sixteen experiments by the second method was 118·8093, the difference between the greatest and least value being 0·228. The mean of ten experiments by the third method was 118·7975, the difference between the extreme values being 0·163. And the mean of ten experiments by the fourth method was 118·7309, the difference being 0·144. The final mean of the 47 experiments was 118·7745; or taking the 26 experiments in which the difference between maximum and minimum was least, 118·8034; taking oxygen at 15·96.—*Ber. Berl. Chem. Ges.*, xxi, 2900, October, 1888. G. F. B.

3. *Studies from the Laboratory of Physiological Chemistry, Sheffield Scientific School of Yale University for the years* 1887–88. Volume III. Edited by R. H. CHITTENDEN, Ph.D. 157 pp. 8vo. New Haven, January, 1889.—The present volume of this series, like those already issued (noticed in vols. xxxii and xxxiii of this Journal) contains a series of important papers upon different subjects in physiological chemistry. They embody the results of work done in the Sheffield Laboratory and show the high position that it occupies as a school of research as well as one of training.

4. *On the divergence of Electromotive forces from Thermo-Chemical data.*—Professor E. F. HERROUN, sums up his research as follows :—

(1.) The primary factor in determining the electromotive force of a Voltaic cell is the relative heat of formation of the anhydrous salts of the two metals employed.

(2.) That the E. M. F. may set up chemical changes of a different direction and character from those predicable from the heat of formation of the dissolved salts.

(3.) That the E. M. F. set up by (1) may be, and usually is supplemented by the energy, or a portion of the energy, due to the hydration or solution of the solid salts, and may have values which accord with the heat of formation of the dissolved salts.

(4.) That in those cases in which there is no chemical attraction, or a very feeble attraction between the water and the salt, the negative heat of solution is derived from sensible heat, and is not supplied by the free energy of the chemical change. All cells in which such salts are employed opposed to zinc should have negative "Thermo voltaic constants" and evolve heat when they send a current forward.

(5.) That when metals, whose salts have purely negative heats of solution, are oppposed to metals whose salts they can replace, the E. M. F. set up is in excess of the total thermal change. Such cells therefore, absorb sensible heat when worked forward.

(6.) That, taking the foregoing facts into consideration, no cell exists which can furnish an E. M. F. in excess of the free energy of the chemical change: i. e. which can convert sensible heat into electrical energy working at uniform temperature (negatives the supposition concerning mercury and other salts.)

(7.) That certain metals have a tendency to form films of sub-salts on their surfaces, the formation of which giving rise, as it does, to a different thermo chemical reaction, naturally furnishes an E. M. F. which does not correspond with the values calculated from the heats of formation of their normal salts (*ex. gr.* copper in cupric chloride, mercury in mercuric chloride, probably silver in most soluble chlorides).

(8.) That the electromotive force of a voltaic cell furnishes a more accurate measurement of this free energy, and therefore of true chemical affinity, than data derived from calorimetric observations."—*Phil. Mag.*, March, 1889, pp. 209–233. J. T.

5. *Behavior of Metals to Light.*—At a meeting of the Physical Society, held in Berlin, Jan. 11, KUNDT gave an account of his experiments on the refraction of light by metals. Metals whose refractive index is large, showed an increase of the angle of deviation of light as the temperature rises; thus proving that the author was dealing with true refraction. A further outcome of his experiments was to show that the velocity of light in metals is dependent on changes of temperature in a way exactly similar to that in which their electrical conductivity is dependent.—*Nature,* Feb. 7, 1889, p. 360. J. T.

6. *Hertz's experiments on Electro-magnetic Waves.*—Professor FITZGERALD and Mr. F. T. TROUTON have repeated Hertz's experiments. Ordinary masonary walls were found to be transparent to electrical waves of ten meters in length, with an apparatus suitable for dealing with definite angles of incidence. With a wall three feet thick reflection was obtained, when "the vibrator" was perpendicular to the place of reflection; "but none, at least at the polarizing angle, when turned through 90° so as to be in it." This decides the point in question, the magnetic disturbance being found to be in the plane of polarization, the electric at right angles.—*Nature*, Feb. 21, 1889, p. 391. J. T.

7. *Electrified Steam.*—"HELMHOLTZ has shown that if an invisible jet of steam be electrified or heated it becomes visible with bright tints of different colors according to the potential or the temperature."—*Nature*, Jan. 24, 1889.

8. *Viscosity of gases at high temperatures and a new Pyrometric method.*—The subject of the viscosity of gases has been investigated by Maxwell, O. E. Meyer, S. W. Holman and others. Dr. Barus in a very exhaustive paper reviews the work of previous observers, and adds valuable results on viscosity at high temperatures. Obermayer had investigated the subject up to 280°, Holman with carbonic acid to 224° and with air to 124°, E. Wiedeman at 100° and 185°. Dr. Barus has carried his observations to 1000°. Temperature was measured by the combination of a porcelain air-thermometer and a thermal junction of platinum and platinum-iridium. Further details of this method of measuring high temperature are reserved for the forthcoming bulletin No. 54, of the U. S. Geological Survey. The observations suggest to Dr. Barus a method of measuring high temperatures which is based upon Meyer's equation of gas transpiration. He entitles the method transpiration pyrometry and gives a comparison of the temperatures measured by this method with those obtained by a direct method, and believes that greater precision in the measurement of high temperature can be obtained by this method than by any other method, not even excepting the method of the porcelain air-thermometer. The paper concludes with a careful discussion of the results upon viscosity which the author has obtained; a plate giving diagrams of the apparatus and the curves which represent the results accompanies the paper. —*Ann. der Physik und Chemie*, vol. xxxvi, 1889, pp. 358–398.

J. T.

II. GEOLOGY AND NATURAL HISTORY.

1. *Brachiospongidæ: On a Group of Silurian Sponges, by Charles Emerson Beecher.* 28 pp. 4to, with 6 plates. Mem. Peabody Mus., Yale Univ., Vol. II, Part 1. New Haven, Conn., 1889.—The first known specimen of the Brachiospongidæ was described and figured, as Mr. Beecher states, by Troost in 1839, but not named. It was from Tennessee. The same species and prob-

ably the same specimen was described by Prof. O. C. Marsh in this Journal in 1867, and named *Brachiospongia Rœmerana.* In 1858, in vol. ii of the Kentucky Geological Survey, the species was named *Scyphia digitata*, by D. D. Owen, from Kentucky specimens, and afterward *Scyphonia digitata.* Mr. Beecher, in his memoir, after presenting further facts respecting the synonymy of the species and describing its geological position as in the Trenton limestone, gives a detailed account of the species under the name *Brachiospongia digitata*, and illustrates it with excellent figures on plates I to IV, showing its various forms, its external and internal structure and its hexactinellid spicules. The number of arms or lobes is shown to be a variable character, the extremes observed being 8 and 12, and the extremes in diameter, 3¼ and 11 inches. Specimens with 12 arms, the maximum number, vary in size from 6 to 10½ inches.

Besides the full account of the Brachiospongia, Mr. Beecher describes and figures also two species of a new genus of Hexactinellid Sponge, named by him *Strobilospongia*, based on specimens collected by himself with the Brachiospongia in Franklin County, Kentucky. The sponge has irregularly rounded lobes grouped about the surface of a stout central mass or stem. The species are *S. aurita* Beecher and *S. tuberosa* Beecher. The memoir is a very important contribution to the science of American Paleozoic Sponges.

2. *On the Waverly Group of Ohio.*—In a paper on the Geology of Licking Co., Ohio, contained in the Bulletin of the Denison University (Granville, Ohio), Vol. IV, Parts 1 and 2, dated December, 1888, Prof. C. L. Herrick continues, from the preceding number, an enumeration of the fossils obtained from the Waverly group and describes and figures (Plates I to XI) some new species. His papers occupy 85 pages of the number. He arrives at the following arrangement of the Waverly series, beginning below:

(1.) Berea or Transition Series, *the western equivalent of the Upper Chemung:* (1) Cleveland shale (local), 50 feet; (2) Bedford shale, 50 ft.; (3) Berea grit, 50–60 ft.; (4) Berea shale (including, besides the Black shale, the greater part of the shale below the Kinderhook), 200–400 feet; (5) Waverly shale, 40 feet.

(2.) Cuyahoga or Waverly Series, *Subcarboniferous:* (1) Kinderhook, Conglomerate I, 50 to 60 feet (not represented in the northern and eastern counties of Ohio); (2) Logan, or the Burlington and Keokuk, Conglomerate II, 100 to 150 feet.

The fossils from the Bedford shale leading to a reference of it to the Chemung are: *Lingula melie* H., *Orbiculoidea Newberryi* H., *Orthis Vanuxemi* H.,* *Chonetes scitula*,* *Ambocoelia umbonata*,* *Hemipronites* sp., *Macrodon Hamiltonæ* H.,* *Microdon bellistratus* Con.,* *Leda diversa*, var. *Bedfordensis*,* *Palæoneilo Bedfordensis* Meek (= var. of *P. constricta*), *Pterinopecten* sp., *Bellerophon Newberryi*,* *B. lineata* H.?, *Loxonema* resembling *L. delphicola*,* *Orthoceras* resembling *O. tintcum*, *Gonia-*

tites resembling a Portage species, *Pleurotomaria* cf. *P. sulcomarginata.* The names marked with an asterisk are Hamilton species, or near them. The Trilobite tribe has its species through the series instead of being absent as in the Chemung and Catskill of New York.

3. *Saccamina Eriana* (Communicated).—I observe that this little fossil has again come under the notice of naturalists.* When specimens from Sandusky were kindly sent to me some years ago by my friend Dr. Newberry, I was, as a paleontologist, naturally disposed to refer them to *Characeæ*, but a comparison with specimens from the French Tertiaries convinced me that this was untenable, and as I found that in form and texture, though not in material, the fossil corresponded to the well-known *Saccamina* of the Carboniferous, I placed it provisionally in that genus.† Subsequently, and apparently without knowing what I had done, Ulrich ("Contributions," Vol. I, 1886), described the Ohio Falls specimens, and referred them to Foraminifera as I had done, but with the new name *Mœllerina Greenei.* I may say that I still hold to my original opinion that these organisms are foraminiferal tests, for the reasons fully stated in my paper in the Canadian Naturalist, 1883, and which I think have not yet been controverted.

I have no other objection to Dr. Williamson's name, *Calcisphæra*, except that it seems certain that the organisms from Kelley's Island are of entirely different nature from those from Wales, and therefore should not bear the same name. I also consider it probable that the specimens described by Ulrich are specifically distinct, though it is not unlikely that the double wall described by him may be a result of difference of preservation rather than original structure. In my specimens the wall seem continuous and granular, having in fact a similar structure to that of other fossil Foraminifera whose tests are composed of calcareous grains. My specimens show some indications that the test was finely porous. This caused me to suggest a possible affinity with *Lagenidæ*, which I find Ulrich also suggests.

J. WM. DAWSON.

Montreal, March 8, 1889.

4. *Ueber eine durch die Häufigkeit Hippuritenartiger Chamiden ausgezeichnete Fauna der oberturonen Kreide von Texas; von Ferdinand Roemer in Breslau. Paleontologische Abhandlungen*, Viertes Band, Heft 4. Berlin, 1888. 4to, 15 pp. 3 plates. —In this valuable paper Dr. Roemer describes with his usual skill, a most interesting fauna from Barton's creek, a few miles west of the city of Austin. The descriptions are excellent and the figures beautiful. Twenty-one species are figured and described, of which eighteen are alleged to be new. As the reviewer has made a special study of the faunal and stratigraphic horizons of these fossils, he would here correct one or two mistakes in the otherwise excellent publication. Instead of being

* Knowlton, this Journal, March, 1889. † Canadian Naturalist, 1883.

from the Austin Chalk of Shumard (Niobrara of M. & H.) as the author asserts, all of these forms came from an entirely different and lower horizon, separated by four distinct subfaunas, a complete stratigraphic and paleontologic non-conformity, and four hundred feet of strata below that horizon, and hence the deductions and correlations of Dr. Roemer are unfounded. The twenty-one species mentioned, together with a half dozen or so in the writer's possession, which escaped Dr. Roemer's attention, are mostly non-criterional genera (except the aberrant bivalves), which range in European terranes from Jurassic to present, but which are especially numerous in the upper Jurassic and Lower Cretaceous, all being found in the European Neocomian, especially the peculiar aberrant bivalves and the Nerineas—the varieties described of the latter having especial Jurassic affinities. Hence, Dr. Roemer's assignment of this fauna to the Upper Turonian horizon is not based upon sufficient evidence either stratigraphical or paleontological. They belong to the Hippurites Limestone of Shumard, whose stratigraphic place as given in my section is in the middle of the Lower American Cretaceous. R. T. HILL.

5. *Shall we teach Geology? A discussion on the proper plan of Geology in modern education;* by ALEXANDER WINCHELL. 217 pages, 12mo.—Prof. Winchell makes in this volume a strong plea for the study of geology in schools and higher institutions of learning, treating at length of its educational value as compared with other subjects of study, its ethical influence, and the bearing of its developments on modern civilization. His large experience enables him to bring forward in illustration, a wide range of facts with regard to the science, and the best methods of instruction.

6. *The Descending Water-current in Plants and its Physiological Significance.* J. WIESNER (*Botanische Zeitung*, Jan. 4, 1889).—In an earlier paper the author gave an account of the supposed existence of a downward movement of water in the branches and stems of plants. In the present communication he points out the bearing of his discovery upon the coördination of the various organs. Experimental proof of the existence of the descending current of water is thought by the author to be afforded in the following way. When a severed leafy shoot of fresh grape-vine is immersed in water, the tissues are more turgescent than before they are covered by water, indicating absorption through the epidermis. If, now, the middle portion of such a shoot is lifted into the air, so that transpiration can go on rapidly, the upper part of the shoot, which is still immersed, will soon become wilted, showing that it is furnishing water to the parts lower down the stem. Assuming that this experiment shows the existence of a downward current, the author passes at once to the application of this fact to the explanation of the development of various parts. He believes, for instance, that the opening of many flowers and flower-clusters is caused largely by the movement of water in the branch or stem, and especially

by the so-called downward current. Other examples cited by the author are the following: (1) Sympodial leafy shoots, (2) Terminal buds, (3) Axillary buds, (4) Acaulescent plants and clusters of radical leaves. All of the cases to which the author applies his hypothesis seem to be perfectly explicable upon the older view that the water in a plant moves in lines of least resistance toward points of consumption or outflow. Thus in the well-known instance of the flow of sap from a maple tree which is tapped, there is undoubtedly, for the time, a descending current; but that there is, under normal conditions, anything answering to this, is not shown by the experiment in question. It should be said, however, that the author promises a more extended communication upon this subject. G. L. G.

7. *Certain Coloring Matters in Fungi.* W. Zopf (Botan. Zeit., Jan. 4, 1889).—The author adds to the long list of pigments found in fungi a few of great interest. He points out the close similarity which exists between the yellow coloring matters in a few fungi and the yellow colors which are derived from some of the higher plants. From some of the tissues of the fungi in question a fatty coloring matter can be isolated by the process of saponification which was suggested by Kühne, and has been successful in other cases; but from certain bacteria which he studied, although the pigment could be obtained, it could not be procured in a condition of purity.

In order to settle the question of the relations of light to the formation of this yellow color, the author cultivated for control, the organism in different nutrient liquids and on different nutrient solids in the light, using the same organisms on precisely the same substances kept in absolute darkness. After the lapse of about a fortnight, the color was found to be as dense in the latter as in the former case. For completeness in nomenclature the author suggests that these substances, so similar in their relations as regards absorption spectra, a series of terms should be given as *anthoxanthin*, *mycoxanthin* and *bacterioxanthin*. The coloring matters of plants are, so far as their physiological significance is concerned, to be regarded as waste products (see Vine's Physiology of Plants, p. 242), which chemically are allied to the aromatic series. Since the fungi have no chlorophyll to begin with, and since, further, these organisms studied by Zopf have the power of producing coloring matters, akin to those of the higher plants, out of colorless substances like gelatin, or agar-agar, some of the pigments must be excluded from the series formerly believed to be products of the degradation of chlorophyll-pigment. G. L. G.

8. *The Bacterial Forms found in Normal Stomachs.*—J. E. Abelous (Comptes rendus, cviii, 310, Feb., 1889) reports the results of his studies in the laboratory of Professor Lannegrace. Besides seven forms of microbes previously known, the author adds nine as occurring in the juices of the healthy stomach upon which experiments were conducted. Proper care appears to have been exercised to exclude all foreign germs from the apparatus used

for withdrawing the liquids of the stomach, and the subsequent cultures seem to have been carried on with care. The conclusions are the following: (1) In the stomach in the normal condition, there are very numerous microbes, some of which can live in strongly acid liquids, and a few of them can exist without air. (2) All of these microbes, when under the conditions of experiment, were found to produce prompt effects on alimentary substances. (3) Taking into account the long time required for some of these microbes to act on the alimentary substances in which they were placed, the author thinks that they must exert their principal effect upon the food after it has passed from the stomach into the intestinal tract. (4) In the intestines, the microbes play a very important part in digestion, since in the experiments, that is to say, under what he calls comparatively unfavorable conditions, many of them can decompose alimentary matters. The author regard his results as confirmatory in all respects of the views expressed by Pasteur and Duclaux. G. L. G.

9. *Mr. Morong's Journey in South America.*—MR. WALTER DEANE, of Cambridge, Mass., sends us the following communication:—"I have received a letter lately from the Rev. Thomas Morong which will interest his friends. The letter is dated Asuncion, Paraguay, Dec. 28, 1888, where he is at present located. Mr. Morong left Boston, July 30, 1888, in the bark Eric J. Ray bound for Buenos Ayres. He went under the auspices of the Torrey Botanical Club, to collect and study the flora of South America, and reached his destination Oct. 8 in just 70 days, after a delightful passage with 'clear days and nights, balmy air and soft breezes.' He has just published a sketch of 'First Glimpses of South American Vegetation' in the February number of the Torrey Bulletin. He writes in excellent spirits and says, 'My health has been first rate ever since I stepped on South American soil and I have not had to take a drop of medicine once.' Ever since he reached Asuncion, which was about the first of November last, he has been most diligently collecting the rich and varied vegetation of that tropical country. He makes the following curious statement:—'The water vegetation disappoints me, not a Potamogeton, or Naiad, or Chara, to be found. But I have seen and collected the Victoria regia, and that makes up in a measure for my disappointment.' Mr. Morong says that he has some 2500 specimens, including about 250 species, already dried and ready to send north. At Asuncion nobody ventures out of doors between the hours of 11 A. M. and 3 P. M. 'for the sun at 115° is a little too much for flesh and blood.' So his botanical tours are made at 5 A. M. about the time when the business of the city begins. 'Botanizing stops when they have a downpour of rain characteristic of that region, for then a regular river runs through the streets, nobody goes out, schools close, stores shut up and all stay at home.' Asuncion is to be his headquarters at present, as he finds that he can accomplish more there than at Buenos Ayres."

10. *The Botanic Garden at Buitenzorg, Java.*—Dr. TREUB (Comptes rendus, cviii, 211, Feb., 1889) says that the Garden comprises three parts. (1), the Botanic Garden, properly so-called, at Buitenzorg, consisting of a collection of between eight and nine thousand species of plants, (2), that at Tjibodas, situated in one of the most mountainous districts, at an altitude of 1500 meters, and (3), the Experimental Garden in the Tjikeumeuh quarter, where are the plantations for raising the plants which possess economic use in the tropics. In the Garden at Buitenzorg, besides the Bureau of Administration, there is a museum, together with an herbarium. There is also a laboratory equipped for physiological and phytochemical research. A photographic studio completes the outfit. The whole institution is now so arranged that botanists can carry on their investigations under the most favorable auspices. In fact, it is the design of the direction to make it as useful to Botany as the zoölogical station at Naples, is to zoölogy. For the support of the establishment, the Government of the Dutch East Indies grants annually the sum of 150,000 francs. G. L. G.

11. *The Structure of the "Crown" of the Root.*—LÉON FLOT (Comptes rendus, cviii, 306, Feb., 1889) gives the results of his examination of the histology of the zone where the stem joins the root. He regards this tissue system as a special structure. Morphologically speaking, this part may be said to possess, besides stem proper, a larger or smaller section of the epicotyledonary axis, and it appears to be derived directly from the nodal portion previously existing in the embryo. G. L. G.

OBITUARY.

Mr. U. P. JAMES, long and well-known to geologists and paleontologists as a student of the fossils of the Cincinnati Group, died at his residence near Loveland, Clermont County, Ohio, on February 25th in his 78th year. He was born December 30th, 1811, in Goshen, New York and went to Cincinnati in 1831 where he has since resided. He established himself in the book-selling and publishing business in connection with his brother Joseph A. James, but afterwards continued the business by himself. As a recreation he interested himself in the sciences of conchology and paleontology and amassed a very large collection of the shells and fossils of the locality in which he lived. Many of the latter were described by himself while others were described in volumes of the Geological Survey of Ohio by Meek, Hall and Whitfield. He published the first catalogue of fossils of the Cincinnati Group, contributed papers to the Cincinnati Quarterly Journal of Science, the Journal of the Cincinnati Society of Natural History, and published the Paleontologist in seven issues. The study of conchology occupied his earlier years, but in later life he devoted his time to paleontology. He was married in 1847 and leaves a widow, two sons and three daughters. The older son manages the business affairs in Cincinnati, while the younger is connected with the U. S. Geological Survey.

APPENDIX.

ART. XXXIV.—*Comparison of the Principal Forms of the Dinosauria of Europe and America;** by Professor O. C. MARSH.

THE remains of Dinosaurian reptiles are very abundant in the Rocky Mountain region, especially in deposits of Jurassic age, and during the past ten years, the author has made extensive collections of these fossils, as a basis for investigating the entire group. The results of this work will be included in several volumes, two of which are now well advanced towards completion, and will soon be published by the United States Geological Survey.

In the study of these reptiles, it was necessary to examine the European forms, and the author has now seen nearly every known specimen of importance. The object of the present paper is to give, in few words, some of the more obvious results of a comparison between these forms and those of America which he has investigated.

With this purpose in view, it will not be necessary to discuss here the classification of the Dinosauria, their affinities, or their origin. These topics will be treated fully in the volumes in preparation. For the sake of convenience, however, the ordinal names proposed by the author, and now in general use, will be employed.

* Abstract of a paper read before Section C, of the British Association for the Advancement of Science, at the Bath Meeting, Sept. 8th, 1888.

Sauropoda.

The great group which the author has called *Sauropoda*, and which is represented in America by at least three well-marked families, appears to be rare in Europe. Nearly all the remains hitherto discovered there have been found in England, and most of them, in a fragmentary condition. The skull is represented only by a single fragment of a lower jaw and various isolated teeth, and, although numerous portions of the skeleton are known, in but few cases have characteristic bones of the same individual been secured.

Quite a number of generic names have been proposed for the remains found in England, and several are still in use, but the absence of the skull, and the fact that most of the type specimens pertain to different parts of the skeleton, render it difficult, if not impossible, to determine the forms described.

In the large collections of *Sauropoda* secured by the author in America, which include the remains of more than one hundred individuals, both the skull and skeleton are well represented. On this material, his classification of three families, *Atlantosauridæ*, *Morosauridæ*, and *Diplodocidæ*, has been based. The *Pleurocœlidæ*, also, appear to be distinct, but the remains at present known are less numerous and characteristic than those pertaining to the other divisions of this group.

In examining the European *Sauropoda* with some care, the author was soon impressed by three prominent features in the specimens investigated:

(1) The apparent absence of any characteristic remains of the *Atlantosauridæ*, which embrace the most gigantic of American forms.

(2) The comparative abundance of another family (*Cetiosauridæ*), nearly allied to the *Morosauridæ*, but, as a rule, less specialized.

(3) The absence, apparently, of all remains of the *Diplodocidæ*.

A number of isolated teeth, and a few vertebræ of one immature individual appeared to be closely related to the *Pleurocœlidæ*, but this, for the present, must be left in doubt.

Among the American forms of *Sauropoda*, the skull is now comparatively well known in the principal families and genera. *Brontosaurus*, *Morosaurus*, and *Diplodocus*, typical of their respective families, are each represented by several skulls, some of which are nearly complete, and characteristic portions are known of the skulls of other genera.

The vertebræ, also, and especially the pelvic arch, afford distinctive characters. By the latter alone, the *Atlantosauridæ* and *Morosauridæ* may be readily distinguished. In the absence of the skull, this is a point of importance in a comparison of European with American forms.

In the *Atlantosauridæ*, the ischia are nearly straight, and when in position, extend downward and inward, meeting on the median line by a symphysis of the two ends, as in crocodiles. In the *Morosauridæ*, the ischia are twisted, and extend inward and backward, with the inner margins alone meeting each other on the median line, the ends being free.

All the ischia of *Sauropoda* known from Europe appear to be of the latter type, although proportionally broader and more massive than those of the corresponding American forms. The ilia and pubes associated with these ischia agree in their main features with those of the American genus *Morosaurus*, so that there can be little doubt that the same general form is represented in both countries.

A striking difference between the *Cetiosauridæ* and the allied American forms is that, in the former, the fore and hind limbs appear to be more nearly of the same length, indicating a more primitive or generalized type. Nearly all the American *Sauropoda*, indeed, show a higher degree of specialization than those of Europe, both in this feature and in some other respects.

The identity of any of the generic forms of European *Sauropoda* with those of America is at present doubtful. In one or two instances, it is impossible, from the remains now known, to separate closely allied forms from the two countries. Portions of one animal from the Wealden, referred by Mantell to *Pelorosaurus* under the name *P. Becklesii*,* are certainly very similar to some of the smaller forms of *Morosaurus*, especially in the proportions of the fore limbs which are unusually short. This fact would distinguish them at once from *Pelorosaurus*, and until the skull and more of the skeleton are known, they cannot be separated from *Morosaurus*, and should be known as *Morosaurus Becklesii*. During the examination of this specimen, which is in the collection of its discoverer, Mr. S. H. Beckles, of St. Leonards, England, the author found, attached to the humerus, portions of the osseous dermal covering, the first detected in the *Sauropoda*, and known only in the present specimen.

A dozen or more generic names have been proposed for the European forms of *Sauropoda*, and of these, *Cetiosaurus*,

* Morris' Catalogue of British Fossils, p. 351, 1854.

Owen, 1841, is the earliest, and must be retained. The remains on which this genus was based are from the Great Oolite, or Middle Jurassic. *Cardiodon*, Owen, 1845, is from nearly the same horizon, and there appears no evidence that the two forms are not identical. *Pelorosaurus*, Mantell, 1850, is from the Wealden, and may be distinct, but, at present, the proof is wanting. *Oplosaurus*, Gervais, 1852, also from the Wealden of England, cannot well be separated from *Pelorosaurus*. *Gigantosaurus*, Seeley, 1869, from the Kimmeridge of the Upper Jurassic, may prove to be different from the above, but the type specimens alone do not indicate it. *Bothriospondylus*, Owen, 1875, is also from the Kimmeridge, and, although the type specimen pertains to a very young, if not fœtal individual, it seems to be distinct, and may be nearly allied to the American genus *Pleurocœlus*. The author failed to find conclusive evidence in the type specimens themselves for the use of the other generic names proposed, namely: *Ornithopsis*, Seeley, 1870, from the Wealden; *Eucamerotus*, Hulke, 1872, Wealden; *Ischyrosaurus* (preoccupied), Hulke, 1874, Kimmeridge; and *Chondrosteosaurus*, Owen, 1876, Wealden.

Æpyosaurus, Gervais, 1852; *Macrurosaurus*, Seeley, 1876; and *Dinodocus*, Owen, 1884, all represent forms from the Cretaceous, but their relations to each other cannot yet be determined.

Discoveries of more perfect specimens may establish the fact that the forms in the different geological horizons are distinct, but as long as the known remains are so isolated and fragmentary, this point must be left in doubt.

The European *Sauropoda* at present known are from deposits more recent than the Lias, and none have been found above the Upper Greensand. In America, this group apparently has representatives in the Trias, was very abundant in the Jurassic, but, so far as now known, did not extend into the Cretaceous.

STEGOSAURIA.

Another group of Dinosaurian reptiles, which the author has called the *Stegosauria*, from the typical American genus *Stegosaurus*, is well represented in European deposits. The remains already discovered are more numerous, and in better preservation, than those of the *Sauropoda*, and the number of distinct generic forms is much larger. The geological range, also, is greater, the oldest forms known being from the Lias, and the latest, from the Cretaceous.

These reptiles, although very large, were less gigantic in size than the *Sauropoda*, and were widely different from them in their most important features. Their nearest allies were the *Ornithopoda*, to which they were closely related.

All the known members of the group appear to have had an osseous dermal armor, more or less complete.

One of the best preserved specimens of the *Stegosauria* in Europe was described by Owen, in 1875, as *Omosaurus armatus*, and the type specimen is in the British Museum. It is from the Kimmeridge Clay (Upper Jurassic), of Swindon, England. The skull is wanting, but the more important parts of the skeleton are preserved. Various portions of the skeleton of several other individuals have also been found in England, but the skull and teeth still remain unknown.

A recent examination of these specimens by the author disclosed no characters of sufficient importance to separate them from the genus *Stegosaurus*, and, as the name *Omosaurus* is preoccupied, they should, for the present, at least, be referred to *Stegosaurus*. The discovery of the skull and the dermal armor may not unlikely prove them to be distinct, but the parts now available for comparison do not alone authorize their separation.

The type specimen of *Anthodon serrarius*, Owen, a fragment of a jaw from South Africa, and now in the British Museum, has teeth so very similar to the American forms of *Stegosaurus*, that, judging from these alone, it would naturally be referred to that genus. *Hylæosaurus*, Mantell, from the Wealden, has teeth of the same general type, but most of those referred to it, by Mantell and others, pertain to the *Sauropoda*. This genus, as well as *Polacanthus*, Hulke, from the same formation, *Acanthopholis*, Huxley, from the Cretaceous, and *Scelidosaurus*, Owen, from the Lias, are known from English specimens, but have not yet been found on the continent. No American forms of these genera have yet been discovered.

An interesting Cretaceous member of this group is the *Struthiosaurus*, Bunzel, 1871, apparently identical with *Danubiosaurus* of the same author, 1871, and *Cratæomus*, Seeley, 1881. It is from the Gosau formation of Austria. Although only fragments of the skeleton and dermal armor are known, some of these are very characteristic. One specimen of the latter, figured by Seeley, and regarded as a dermal plate, bearing a horn-like spine "exactly like the horn-core of an ox,"* is very similar in form to some problematical fossils from America, the exact horizon of which is in doubt.†

* Quarterly Journal of the Geological Society of London, vol. xxxvii, Plate XXVIII, fig. 4, 1881.

† Additional remains secured during the past season prove conclusively that some of these "horn-cores," if not all, were attached to the skull in pairs, and one specimen found in place has since been described by the author as *Ceratops montanus* (This Journal, vol. xxxvi, p. 477. December, 1888). It is from the Laramie formation of Montana. Others have been found in Colorado and in Wyoming. These are all much larger than the European specimens.

Palæoscincus, Leidy, 1856, from the Cretaceous, and *Priconodon* of the author, 1888, from the Potomac formation, are, perhaps, allied forms of the *Stegosauria*, but, until additional remains are found, their exact affinities cannot be determined. Apparently, the oldest known member of this group in America is the *Dystrophæus*, Cope, 1877, from the Trias of Arizona. In Europe, none have yet been found below the Jurassic. The *Euskelesaurus*, of Huxley, 1867, from the Trias of South Africa, is apparently a member of this group.

ORNITHOPODA.

The great group which the author has called the *Ornithopoda* is well represented in Europe by *Iguanodon* and its allies. The remarkable discoveries in the Wealden of Belgium, of a score or more skeletons of *Iguanodon*, have furnished material for an accurate study of the genus which they represent, and, indirectly, of the family. The genus *Iguanodon*, founded by Mantell in 1824, is now the best known of European forms, and need not here be discussed. *Hypsilophodon*, Huxley, 1870, from the Wealden, is likewise well represented, and its most important characters fully determined. The other genera of this group, among which are *Mochlodon*, Bunzel, 1871, *Vectisaurus*, Hulke, 1879, *Orthomerus*, Seeley, 1883, and *Sphenospondylus*, Seeley, 1883, are described from less perfect material, and further discoveries must decide their distinctive characters.

None of these genera are known from America, but allied forms are not wanting. A distinct family, the *Hadrosauridæ*, is especially abundant in the Cretaceous, and another, the *Camptosauridæ*, includes most of the Jurassic species. The latter are the American representatives of the *Iguanodontidæ*. The nearest allied genera are, apparently, *Iguanodon* and *Camptosaurus* for the larger forms, and *Hypsilophodon* and *Laosaurus* for those of small size. A few isolated teeth from each country suggest that more nearly related forms may at any time be brought to light.

Many generic names have been proposed for members of this group found in America and in Europe, but, in most cases, they are based on fragmentary, detached specimens, which must await future discoveries before they can be assigned to their true place in the order.

As a whole, the European *Ornithopoda* now known seem to be less specialized than those of America, but additional discoveries may modify this opinion. The geological range of this group, so far as known, is essentially the same on each continent, being confined to the Jurassic and Cretaceous.

There is some evidence, from footprints, at least, that, in America, the order was represented in the Trias.

THEROPODA.

The carnivorous *Dinosauria* have all been included, by the author, in one order, *Theropoda*, although there are two or three suborders quite distinct from each other. This great group is well represented both in Europe and America in the Trias, is especially abundant in the Jurassic, and diminishes in the Cretaceous, at the close of which, it apparently becomes extinct.

The typical genus is *Megalosaurus*, Buckland, 1824, the type of which was the first Dinosaurian reptile described. Although its remains are comparatively abundant in Europe, they have been found only in a fragmentary condition, and many important points in the structure of the skull and skeleton are still in doubt.

The oldest representatives of this group in Europe are *Thecodontosaurus*, Riley and Stutchbury, 1836, and *Plateosaurus*, von Meyer, 1837, both from the Trias. The former genus is from the lower horizon, near Bristol, England; the latter, from the Keuper of Germany. *Zanclodon*, Plieninger, 1846, is from the same horizon as *Plateosaurus*, and appears to be the same thing. *Massospondylus*, Owen, 1854, from the Trias of South Africa, is apparently a form allied to *Thecodontosaurus*. The nearest American genus is *Anchisaurus*, two species of which are known from the Connecticut River sandstone.

The most interesting member of the *Theropoda* known in Europe is the diminutive specimen described by Wagner, in 1861, as *Compsognathus longipes*. The type specimen, the only one known, is from the lithographic slates of Solenhofen, Bavaria, and is now preserved in the museum in Munich. Fortunately, the skull and nearly all the skeleton are preserved, and as it has been studied by many anatomists, its more important characters have been made out. It is regarded as representing a distinct suborder, and no nearly related forms are known in Europe Its nearest ally is probably the specimen from Colorado, described by the author, in 1881, as *Hallopus victor*. This animal was about the same size as *Compsognathus*, and resembles it in some important features. It is probably from nearly the same geological horizon, but may be somewhat older Each of these specimens appears to be unique, and until a careful comparison of the two is made, their relations to each other can only be conjectured.

The American representative of *Megalosaurus* is apparently *Allosaurus*, a genus established by the author, in 1877. The type specimen is from Colorado, from a higher horizon in the Jurassic than that of *Megalosaurus*. Nearly every part of the skeleton of this genus is now known, and the more important portions have been described and figured by the author. *Creosaurus*, also from the Jurassic, is an allied form, and *Dryptosaurus*, from the Cretaceous, is, perhaps, also closely related. A very distinct form in the Jurassic is *Labrosaurus*, described by the author, in 1879. It is known from detached specimens only, but these, especially the jaws, edentulous in front, show it to represent a distinct family.

The most perfectly known of American *Theropoda*, and by far the most interesting, is the genus *Ceratosaurus*, founded by the author, in 1884. This is the representative of a very peculiar family, which differs in some important respects from all other known Dinosaurs. The skull and nearly all the various parts of the skeleton are known. When found, they were entire, and in the position in which the animal died. The skull and some of the more interesting parts of the skeleton have been figured by the author, and all will soon be fully described.

The skull bears a large elevated horn-core on the median line of the nasals. The cervical vertebræ differ in type from those of any other known reptiles, having the centra plano-concave. All behind the axis have the anterior end of each centrum perfectly flat, while the posterior end is deeply cupped. This genus, moreover, differs from all known Dinosaurs in having the elements of the pelvis (ilium, pubis, and ischium) coössified, as in all existing birds. The metatarsals, also, are firmly united, as in birds. No representatives of the *Ceratosauridæ* are known in Europe.

In conclusion, it may safely be said that the four great groups of *Dinosauria* are each well represented both in Europe and America. Some of the families, also, of each order have representatives in the two regions, and future discoveries will doubtless prove that others occur in both.

No genera common to the two continents are known with certainty, although a few are so closely allied, that they cannot be distinguished from each other by the fragmentary specimens that now represent them. It must be remembered that the great majority of genera have been named from portions of skeletons, of which the skull was unknown, and until the latter is found, and definitely associated with the remains described, the characters and affinities of the genus can be only a matter of conjecture, more or less definite, in proportion to the perfection of the type specimens.

From Asia and Africa, also, a few remains of Dinosaurs have been described, and the latter continent promises to yield many interesting forms. Characteristic specimens, representing two genera, one apparently belonging to the *Stegosauria*, and one to the *Theropoda*, are already known from South Africa, from the region so rich in other extinct Reptilia.

From Australia, no *Dinosauria* have as yet been recorded, but they will undoubtedly be found there, as this great group of Reptiles were the dominant land animals of the earth, during all Mesozoic time.

ART. XXXV.—*Notice of New American Dinosauria;* by O. C. MARSH.

IN the large series of Dinosaurian remains brought together by the writer, in the last few years, and now under investigation, there are a number of new forms, some of which are briefly noticed below. These will all be fully described and figured in the memoirs now in preparation, by the writer, for the United States Geological Survey.

Anchisaurus major, sp. nov.

The remains of this reptile are from the sandstone of the Connecticut River valley, which has long been known for the great variety of footprints it contains, especially those supposed to have been made by birds. The extreme rarity of any bones in these beds is equally well known, not more than half a dozen finds having yet been made, and only a few of these of much scientific interest. A portion of a skeleton found near Springfield, Mass., and described by Hitchcock, in 1865, as *Megadactylus*, has hitherto been by far the most important of these discoveries. It is a typical member of the order *Theropoda*, and has apparently for its nearest allies in the old world, *Thecodontosaurus*, from the Trias of England, and *Massospondylus*, from the same formation in South Africa.

The remains here described represent a later discovery, in 1884, near Manchester, Conn., in essentially the same horizon as the Springfield specimen. They indicate an animal of larger size, but in many respects nearly allied to the one described by Hitchcock. Both apparently belong to the same genus, which the writer has called *Anchisaurus*, as the name first given was preoccupied.

The present specimen is part of a skeleton which was probably complete, and in position, when discovered, but for want of proper appreciation at the time, only the posterior portion was secured. This consists of the nearly entire pelvic arch, with both hind limbs essentially complete, and in position. As this was one of the animals that are supposed to have made the footprints, one of the hind feet is figured below.

FIG. 1.

FIGURE 1.—Right hind foot of *Anchisaurus major*, Marsh; front view. One-fourth natural size.

In the present specimen there are only three sacral vertebræ. All the dorsal vertebræ preserved have their articular ends biconcave, or nearly plane.

The ilium has a slender preacetabular process, thus differing from most of the other *Theropoda*. The ischia are very slender, and are directed backward. For the posterior half of their length, they are closely adapted to each other.

The known remains of this species indicate an animal about six or eight feet in length.

Morosaurus lentus, sp. nov.

One of the most interesting specimens of *Sauropoda* in the Yale Museum pertains to a species of *Morosaurus* much smaller than *M. grandis*, the type, and differing materially in other respects. The skull is not known, but nearly all the important parts of the skeleton are well represented, and in excellent preservation. The individual was not fully adult, and hence, the elements of the vertebræ and sacrum are, in most cases, separate, thus affording special facilities for investigation.

The limb bones and feet show that the fore and hind legs were much shorter than those of the other species of the genus. The vertebræ, also, are shorter, more massive, and the cavities in them, smaller. All parts of the skeleton preserved are of similar density, indicating that the whole osseous structure of the animal was more solid than any other of the known *Sauropoda*. The vertebræ of the cervical and dorsal regions have their centra more depressed than in the other species of this genus, and may easily be distinguished by this feature alone. The neural arch rests directly upon the centrum, instead of being elevated on pedestals above the articular faces. This feature is well shown in the figure below.

FIG 2.

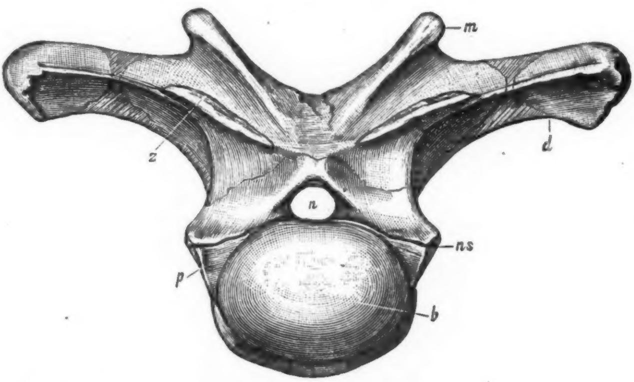


FIGURE 2.—Posterior cervical vertebra of *Morosaurus lentus*, Marsh; front view. One-fifth natural size.

The type specimen of the species here described indicates an animal about thirty feet in length. The known remains are from the Atlantosaurus beds of the Upper Jurassic, in Wyoming.

Morosaurus agilis, sp. nov.

A second new species, which apparently belongs to the same genus, is represented by the posterior half of the skull, the anterior cervical vertebræ, and other parts of the skeleton. This animal was in direct contrast with the one last described, the skull and skeleton being especially light and delicate in structure for one of the *Sauropoda.* It was also much smaller in size, being the most diminutive known member of the genus, probably not more than fifteen feet in length.

The figure below represents the back of the skull with the atlas attached, and the postoccipital bones in place. The axis and third cervical were also found in position. These will serve to distinguish the present species from the others of the genus, as they are proportionally much longer, and of lighter structure.

FIG. 3.

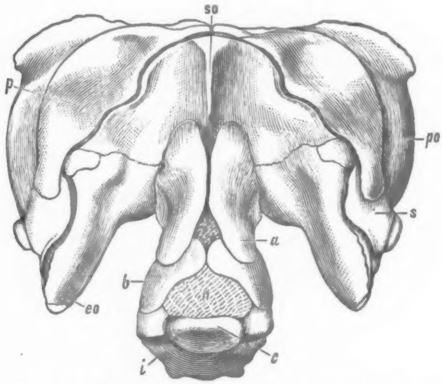


FIGURE 3.—Skull of *Morosaurus agilis*, Marsh; posterior view. One-half natural size.

The hind feet of the present specimen agree in general structure with those of *Morosaurus grandis*, but differ in having the first digit unusually large and massive in comparison with the others. The third, fourth, and fifth, are especially slender.

This interesting specimen was found in the Upper Jurassic beds of Colorado, by Mr. M. P. Felch, whose researches have brought to light so many important remains of the *Dinosauria.*

Ceratops horridus, sp. nov.

The strange reptile described by the writer as *Ceratops montanus** proves to have been only a subordinate member of

* This Journal, vol. xxxvi, p. 477, Dec., 1888. *See also* p. 327 of the present number. The specimen figured in vol. xxxiv, p. 324, may prove to belong to the same genus.

the family. Other remains received more recently indicate forms much larger, and more grotesque in appearance. They also afford considerable information in regard to the structure of these animals, showing them to be true *Stegosauria*, but with the skull and dermal armor strangely modified and specialized just before the group became extinct.

The vertebræ, and the bones of the limbs and of the feet, are so much like the corresponding parts of the typical *Stegosaurus* from the Jurassic, that it would be difficult to separate the two when in fragmentary condition, as are most of those from the later formation. The latter forms, however, are of larger size, and nearly all the bones have a peculiar rugosity, much less marked in the Jurassic species. In the form here described, this feature is very conspicuous, and marks almost every known part of the skeleton.

In the type specimen of the present species, the posterior horn-cores are much larger than these appendages in any other known animal, living or extinct. One of them measures at the base, no less than twenty-seven inches, and about sixteen inches around, half way to the summit. Its total height was about two feet. In general form, these horn-cores resemble those of *Ceratops montanus*, but the anterior margin is more compressed, showing indications of a ridge.

The top of the skull, in the region of the horn-cores, is thick and massive, and strongly rugose.

This skull as a whole must have had at least fifty times the weight of the skull of the largest *Sauropoda* known, and this fact will give some idea of the appearance of this reptile when alive.

As previously stated, the posterior pair of horn-cores of this family are hollow at the base, and in form and surface markings are precisely like those of the *Bovidæ*. The resemblance is so close that, when detached from the skull, they cannot be distinguished by any anatomical character. This accurate repetition, in later and still existing forms, of the highly specialized weapons of an extinct group of another class is a fact of much interest.

The present specimen is from the Laramie formation of Wyoming, but fragmentary remains, which may be referred provisionally to the same species, have been found in Colorado.

Hadrosaurus breviceps, sp. nov.

An interesting specimen in the Yale University Museum, from Montana, indicates a large Dinosaur, apparently belonging to the genus *Hadrosaurus*, and hitherto unknown. It is the dentary portion of the right maxillary, and is so characteristic, that it is here briefly described and figured. Its main features are well shown in figures 4 and 5 below.

The teeth are very numerous, and form a tessellated surface, as in *Hadrosaurus Foulkii*, Leidy, but they are more elongate, and the outer enamelled faces ard less distinctly rhomboid in form. The grooves, also, in which the inner surfaces of the fangs were inserted, are less regular, than in that species.

FIG. 4.

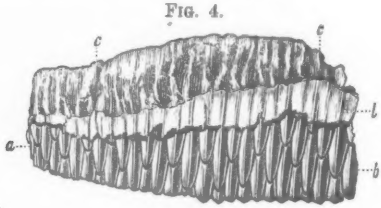


FIG. 5.

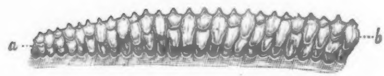


FIGURE 4.—Right maxillary of *Hadrosaurus breviceps*, Marsh; outside view.
FIGURE 5.—The same jaw; showing worn surface of teeth.
Both figures are one-fourth natural size.

The present specimen is from the Laramie formation of Montana.

Hadrosaurus paucidens, sp. nov.

In strong contrast with the species above described is another from the same region and same formation. The best preserved specimen that now represents it is a left maxillary, nearly complete. With this was found some other portions of the skull, but the maxillary affords the best distinctive characters. All, however, indicate a skull of extreme lightness and delicacy of build for one of the *Ornithopoda*. The maxillary is especially slender, and the anterior and posterior extremities are pointed. The middle of the bone is more massive, but yet very light for this portion of the skull. The teeth are of the general type of those in this genus, but are comparatively few in number, and only one row appears to have been in service.

The maxillary preserved is about ten inches in length, and three inches high near the center. The row of teeth in use contains about thirty.

The remains on which the present species is based were found in 1888, in the Laramie formation of Montana, by Mr. J. B. Hatcher, of the United States Geological Survey.

New Haven, Conn., March 25, 1889.

CONTENTS.